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CHANGING INNOVATION SYSTEMS IN THE DEVELOPING COUNTRY CONTEXT: TECHNOLOGY TRANSFER AND THE NEW TECHNOLOGICAL CAPABILITIES IN THE MATERIALS INDUSTRY IN TURKEY

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Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Science and Technology Policy Studies

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

Signature: ……………………..

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UNIVERSITY OF SUSSEX

Elif Esin Yoruk Doctor of Philosophy

Changing Innovation Systems in the Developing Country Context: Technology Transfer and the New Technological Capabilities in the Materials Industry in Turkey

ABSTRACT

This thesis is concerned with analysing the extent that technology transfer contributes to the improvement and development of technological capabilities through learning at the firm level in a developing country context, and the impact of this process on the emergence and changes of key characteristics of innovation systems. Therefore, it investigates how innovation systems change over time and how they were influenced by technology transfer activities in the materials industry in Turkey between 1967 and 2001. As a contribution to the theory, the concept of technological capability is used as a bridge from the notion of technology transfer to that of the innovation system. Innovation system studies tend to rely on R&D statistics via innovation surveys for empirical analyses, whereas these could well be defined by qualitative data collected on technological capabilities through interviews. This thesis follows the latter route within an analytical framework that is designed for a firm-centred analysis. The qualitative data obtained from the interviews were transformed into categorical quantitative data to be used in multinomial logistic regression and linear regression analyses.

This thesis shows firstly that firm-level capabilities were increasing over time during the period from 1967 to 2001 in the materials industry in Turkey. They were also increasing over time with the rising level of technological capabilities in the firms and the firms' involvement in both collaborative relationships and in-house activities. Secondly, firm-level capabilities shape the way the interactions in the innovation system change. As their level of technological capabilities deepen, firm interactions increase and shift to a moderate degree in plausible directions towards domestic agents, which are predominantly universities and research institutes. These findings support the firm-driven nature of the innovation systems.

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LIST OF ABBREVIATIONS

ACR	Arm's Length Contractual Relationships
AIST	Agency of Industrial Science and Technology, Japan
BEC	Broad Economic Categories
BSc	Bachelor of Science
BTYK	Supreme Council of Science and Technology (in Turkey)
CMC	Ceramic Matrix Composites
CPI	Consumer Price Index
CVD	Chemical Vapour Deposition
DOA	Direct Offset Agreements
DoC	U.S. Department of Commerce
EU	European Union
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GFI	Gross Fixed Investments
GNP	Gross National Product
GRI	Government Research Institute
GTIP	Customs Tariff and Statistics Position
ICT	Information and Communication Technologies
IMF	International Monetary Fund
ITC	Indigenous Technological Capabilities
JFCA	Japan Fine Ceramics Association
KOSGEB	Small and Medium Sized Industry Development Organisation (in Turkey)
MAM (TUBITAK-MAM)	Marmara Research Centre (in Turkey)
MITI	Ministry of International Trade and Industry (in Japan)
MMC	Metal Matrix Composites
MNE	Multinational Enterprise
MPIF	U.S. Metal Powder Industries Federation
MSE	Materials Science and Engineering
MSEL	Materials Science and Engineering Laboratory
NDT	Non-destructive Testing
NGO	Non-Governmental Organisation
NSI	National Systems of Innovation
OCR	Obligational Contractual Relationships
ODM	Own Design Manufacturing
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturing
OLS	Ordinary Least Square
OP	Outward Processing
OTA	United States Congress, Office of Technology Assessment
P/M	Powder Metallurgy
PMC	Polymer Matrix Composites
PSBR	Public Sector Borrowing Requirements
PSZ	Partially Stabilized Zirconia
PVD	Physical Vapour Deposition
R&D	Research and development

RTM	Resin Transfer Moulding
SCI	Scientific Citation Index
SIS	Sectoral Innovation Systems
SMC	Sheet-Molding Compound Process
SME	Small and Medium Sized Enterprise
SPO	State Planning Organisation (in Turkey)
S&T	Science and Technology
STP	Science and Technology Policy
TARAL	Turkish Research Area
TEKMER	Technology Development Centre (in Turkey)
TIDEB (TUBITAK-TIDEB)	Support and Assessment Unit for Technological Innovation (in Turkey)
TUBITAK	The Scientific and Research Council of Turkey
TL	Turkish Lira (Turkish currency)
TR	Technological Regime
TS	Technological Systems
TTGV	Turkish Technology Development Foundation
TURKSTAT	Turkish Statistical Institute (TUIK in Turkish)
UNIDO	United Nations International Development Organisation

CHAPTER 1   INTRODUCTION

Transfer of technology has widely been accepted as the main channel for acquiring technological capabilities, particularly in the firms of developing countries. During the 1960s and 70s, transfer of technology was referred to as approximately equal to just the import of production technologies, and scholars talked about 'appropriate technologies' to be transferred by developing countries so that they could benefit from the transfer (Cooper and Sercovitch, 1970; Stewart, 1985; Hoffman and Girvan, 1990). This view concentrated on 'the successful use of imported technology'. Even to be able to use the imported technology successfully, firms need to interact further. Set-up and training activities attached to the importation process provide the basis for further interactions among the firms where the knowledge flows take place, maybe in their simplest form. Later, during the 1980s and 1990s, the research tackled not only the simple import of technology as embodied in the machines, but the technology transferred from human to human which had a significant tacit character also started to attract attention in the literature. Transfer of technology with tacit and codified elements of knowledge is thought to provide the basis for the accumulation of technological capabilities in the firm (Bell and Pavitt, 1993, 1995). Later still, the literature moved on, with noteworthy studies emphasizing that the success of technology transfer in a developing-country firm depended on the firm's technological efforts or mastery, the prior knowledge base and the absorptive capacity (Dahlman and Westphal, 1982; Lall, 1987, 1992; Cohen and Levinthal, 1990; Kim, 1997, 1998,1999).

"Firms almost never innovate in isolation" (Edquist, 1997:1). They need to interact (at least with their suppliers of raw materials, of technology, etc.) to produce, to acquire technological capabilities and to innovate. Interactions with other institutions allow firms to transfer the technology they need for production and innovation. By the end of the 1980s and beginning of the 1990s, a new approach called 'systems of innovation' emerged in the literature. This looks into the networks of interactions of firms with other firms and institutions inside a country or a region or an industry, and states that an organised environment (in a country) where firms and institutions could interact with each other would allow firms to be more productive and innovative. These views were also supported by extensive case studies, particularly from the developed and also some developing countries. Yet, existing studies of the systems of innovation concept tries to clarify it by constructing definitions and aiming to form a general framework from a theoretical perspective. As Edquist (1997) emphasises, still many points remain to be worked on and illuminated. For instance, the innovation systems concept remained isolated on its own, focussing on the interactions among the agents of the system at a broad level where empirical analysis is hard to conduct because of the many parameters the concept has to deal with. That is why extensive case studies on developed countries where there are reliable data on R&D, etc., have been mostly investigated. On the other hand, as long as the skills and knowledge embodied in workers, facilities and organisational systems might be transformed into both production and technical change activities through interactions between elements of the system, technological capabilities act as a bridge from technology transfer towards innovation systems. Innovative capacity itself has a strong relation to the accumulation of technological capabilities through learning. If learning is considered to be firm-centred, then technological capabilities might be analysed at the firm level and, moreover, innovative activity is said to be a function of the firm structure at the micro level. Therefore, innovative activity lies at the heart of the 'system', having a cumulative character arising from the accumulation of technological capabilities and supported strongly with networks of firms.

Thus, this study mainly aims to provide a framework for the emergence of innovation systems in a developing-country context, by using the contribution of technology transfer activity to the dynamic assimilation of firm-level technological capabilities and knowledge integration processes of the firm as tools of analysis. Therefore, this study aims to answer the principal research question below by staying within the boundaries of the 'firm' and two specific and contrasting segments of the materials industry in Turkey:

How do innovation systems emerge and change in a developing-country context, and how are they influenced by the technology transfer activities?

A two-stage research is designed to work on the major objectives of the study and to answer the sub-questions below, which elaborate the main research question:

- *How does the transfer of technology influence technological capabilities at the firm level in the materials industry in Turkey?*
- *How do the increments in technological capabilities from the technology transfer processes influence the emergence and the elements of the system of innovation in the materials industry in Turkey?*

On the whole, this research is concerned with analysing the extent to which technology transfer contributes to the development and improvement of technological capabilities through knowledge integration and learning at the firm level in a developing country, and the impacts of this process on the emergence and alteration of innovation systems. Therefore, the study will be built on the literatures about the theory of the firm, technology transfer, technological capabilities and innovation systems. The research questions intend to examine the importance of a set of variables on the emergence and change of innovation systems in a developing country context for two contrasting segments of the materials industry, by taking the starting point of firm-level activities. The main emphasis of the research will be on trying to shed light on the emergence of innovation systems in the developing-country context, using the "firm" as a primary tool of analysis, aiming to use the knowledge about its linkages with other firms and research institutions both within the national borders and internationally. The firm's own indigenous capabilities will be used as devices to explain the extent of these linkages.

This thesis is structured into seven chapters. The first chapter is this introduction. The second chapter presents the theoretical framework in which this study is entrenched. The theories of the firm, technological capabilities at the firm level, technology transfer in a developing-country context and systems of innovation literatures are widely discussed in this chapter, as well as highlighting the connections between these approaches. It argues that firm-level technological capabilities serve as a bridge and a useful tool of analysis from the technology transfer concept in developing countries towards the systems of innovation concept if knowledge flows are focussed upon, rather than the broader context of innovation systems approaches. It concludes with the analytical framework employed in this research to tackle the proposed research questions.

Chapter 3 elaborates the analytical framework and provides a research design with an explanation of restrictions about that research design. Initially, the chapter presents the rationale for selecting the materials industry in Turkey, with the means of comparison – i.e. science-based and mature segments of the materials industry, the sample firms examined, the reliability of the sample, the method of data acquisition, and the unit of analysis. Then, the key concepts and their operationalisation to form the variables with their categories are described. Following those accounts, the reasons for selecting the statistical analysis methods and data configuration are explained. Finally, the models for statistical analyses are introduced.

In Chapter 4, the first part provides a general overview of the Turkish economy and the second part gives information on the Turkish innovation system policy. The Turkish economy's structure from the 1960s to 2005 is explained with statistics from industry, growth, trade and finance compared in three periods, which reflect three different eras (pre-1980, 1981-1996 and 1997 onwards) in the economy. This part also includes a brief section on the materials industry in general – i.e. about the types of products produced in this industry, which clarifies the justification for the basis of comparison of the science-based and mature segments of the industry throughout the thesis. This is followed by the exportation and importation figures of functional and structural materials in the Turkish materials industry. In the second part, the policies introduced for the Turkish innovation system are mostly discussed, because the efforts up to recent times have largely been on creating policy tools. The elements of an innovation system – i.e. system interactions and actors in Turkish industries – are also touched upon regarding their deficiencies in the policy documents.

Chapters 5 and 6 introduce the empirical evidence on the emergence of an innovation system in the Turkish materials industry, based on the technology transfer by firms improving their firm-level technological capabilities. Chapter 5 investigates the relation between the technology transfer and technological capabilities and Chapter 6 investigates the relation between the technological capabilities and the system of innovation, using firm-level technological capabilities as a bridge between two other concepts. In Chapter 5, the analysis of the firms in the materials industry in Turkey shows how firm-level capabilities were increasing over time during the period 1967 to 2001 in the materials industry in Turkey; also, how they were increasing over time with the increasing level of absorptive capacity in the firm and firm-level involvement in collaborative relationships. In Chapter 6, the analysis of the firms in the materials industry in Turkey shows how firm-level capabilities shape the way the innovation system's interactions change. It also shows how firm interactions increase and seem to shift around in plausible directions towards domestic agents, as the firm-level technological capabilities deepen.

Chapter 7 builds the main conclusions of the thesis and also its theoretical, methodological and empirical contributions to the literature.

There are four appendices attached to the main text. For readers who are interested in further technical details, Appendix A provides in-depth information on the materials industry, all types of production processes used and the products produced in the science-based and mature segments of the industry. Appendix B presents the whole questionnaire used during face-to-face interviews with the key informants in the firms. Appendices C and D present the original tables obtained from the cross-tabulation analyses, which are collapsed down to more focussed tables in Chapters 5 and 6.

CHAPTER 2 TECHNOLOGY TRANSFER, TECHNOLOGICAL CAPABILITIES IN THE FIRM AND THE INNOVATION SYSTEMS

2.1 Introduction

This chapter aims to identify and locate the research questions that emerged in the previous chapter in the conceptual context. To do so it discusses the literature on theories of the firm, technology transfer to developing countries, technological capability accumulation at the firm level, and the innovation systems. It also focuses on the relations between technology transfer and technological capability accumulation in the firm, as well as between technological capability accumulation and the innovation systems concepts.

The chapter is structured in eight parts. Section 2.2 has a brief presentation on theories of the firm and the technological capability concept with its definitions and types in the literature. Section 2.3 discusses the technology transfer concept. Section 2.4 focuses on research in the literature that attempts to highlight the relation between technology transfer and technological capability. Section 2.5 tackles different innovation systems approaches. Section 2.6 relates technological capability accumulation to the innovation systems approach. Section 2.7 discusses the literature on relating technological capabilities to innovation systems concept. Section 2.8 forms the conclusions and 2.9 presents the analytical framework to be detailed in the methodology of Chapter 3.

This study starts with the research question: “How does transfer of technology influence technological capabilities at the firm level in the materials industry in Turkey?” The following four sections will try to locate the concepts involved in this question in the related literature.

2.2 Theories of the Firm and Technological Capabilities

Several theories on the firm have been proposed to understand the underlying facts on how firms deal with knowledge. Firms need some penetration of knowledge into their boundaries by any means in order to survive.

Neoclassical economics tends to treat knowledge as available to every firm, in the same context and in the same amount. Moreover, every firm can handle this bunch of knowledge acquired in the most optimal way. Thus, contrary to what is happening in the real life, knowledge acquisition and how it is tackled by the firm is not actually a concern for this simple form of neoclassical economics. The assumption of 'perfect information' is required for 'perfect markets' to represent the best form of economic organisation. More realistic sets of assumptions made by many neoclassical economists today include such phenomena as 'asymmetries of information', in which some agents have access to more or better information than others.

Fransman (1994: 714) classifies several well-known approaches to the firm as "responses to information-related problems". They all start with the definition of information, which says that it is not explicit and assume that it is unevenly distributed among the agents. Fransman (1994) lists Alchian and Demsetz's (1972) theory of the firm as joint team production, Jensen and Meckling's (1976) theory of the firm as a nexus of contracts between principals and agents, Coase's (1937) approach to the firm and Williamson's (1975) transaction-cost theory with bounded rationality among such a group of theories of the firm.

As a more radical response to the neoclassical economics literature, the studies of Nelson and Winter (1982), Chandler (1990), Penrose (1995) and Teece et al. (1997) focus on the 'firm' as a repository of specific knowledge. This is known as the resource-based view of the firm. Chandler (1990) defines the firm as an organisational structure which depends on knowledge, skill, experience and teamwork – on the organised human capabilities essential to exploit the potential of technological processes. Fransman (1994: 715) describes Nelson and Winter's approach as that firms develop routines as a response to information-related problems and it is in the routines that a firm's organizational knowledge is stored. So, routines are the repositories of the firms where specific knowledge, skill, experience is located. Basically, Nelson and Winter's (1982) study of the 'firm' paved the way for further studies on the 'technological capability' concept at the firm level. This happened when it is shown that no firm is alike and each firm has its own routines with its specific knowledge along with its unique levels of absorption and perception. In another study, Nonaka et al. (2000: 6-17) formulate the firm as a knowledge-creating entity in a continuously dynamic environment. They first criticise transaction-cost theory because it fails to grasp knowledge dynamics by concentrating only on transactions of knowledge base through market mechanisms. Then they criticise the resource-based view of the firm because though it deals with dynamic capabilities, the firm is just an information-processing entity and it fails to address the dynamism in which the firm continuously builds such resources within the dynamic process of knowledge creation. Nonaka et al. (2000: 16) state that knowledge creation is the most important activity of the firm. They provide the framework for a continuous and dynamic process, in which tacit knowledge held by individuals is converged and amplified by the spiral of knowledge through socialization, combination, externalisation and internalisation of knowledge.

All these approaches lead to the fact that firms need to accumulate technological capabilities and improve them in order to survive in a competitive environment. In the literature, technological capabilities are discussed at the firm level, industry level (Bell and Pavitt, 1995; Kim, 1997a, 1997, 1998, 1999) and national level (Lall, 1992). The smallest unit in which technical change is absorbed and technological capabilities are built on is the firm, the results of which are then reflected onto the industries at the meso level and to the country at the macro level.

Lall (1987) uses the term 'indigenous technological effort' in mastering new technologies, adapting them to local conditions, improving on them and even exporting them. Dahlman and Westphal (1982) call this 'technological mastery', which is operationalised through 'technological effort' to assimilate, adapt and create technology.[1] According to Bell and Pavitt (1993:163-4), technological capabilities

consist of the resources needed to generate and manage technical change, including skills and experience, and institutional structures and linkages. They refer to technological learning (technological accumulation) as any process by which resources for generating and managing technical change (technological capabilities) are increased or strengthened. A clearer definition of technological capabilities is asserted as the resources needed to generate and manage improvements in processes and production

[1] Quoted from Figuieredo (1999).

organisation, products, equipment and engineering projects. They are accumulated and embodied in individuals (skills, knowledge and experience) and organisational systems (Bell and Pavitt, 1995).

Bell and Pavitt (1995) distinguish between basic *production capabilities* and *technological capabilities* of the firm. They strongly propose that basic production capabilities are different from technological capabilities, which are indeed identified as capabilities to generate and manage technical change. The former does not possess such capabilities. Previously, Bell and Pavitt (1993: 159) distinguished between two stocks of resources at the country level: (i) *technological capabilities*, the skills, knowledge and institutions that make up a country's capacity to generate and manage change in the industrial technology it uses, and (ii) *production capabilities*, the capital goods, knowledge and labour skills required to produce industrial goods with 'given' technology. They explicitly state that by 'technological accumulation' they mean the accumulation of the first of these stocks.

In a later study, Bell and Albu (1999: 1724) concentrate on the depth or innovativeness of technological capabilities rather than its functionality, emphasizing the *knowledge-using* and *knowledge-changing* elements of technological capabilities. According to their classification, the knowledge-using elements are involved in maintaining or expanding capacity using given modes of production, training workers in established operating procedures, the imitation of production techniques used by the neighbouring firms; whereas knowledge-changing elements are involved in the management of innovation processes, in product design and development, or in the search for selection, adaptation and assimilation of new product or process technology.

According to Kim (1997a: 86) technological capability is "the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies." Kim (1999: 111) classifies technological capability in three categories, quoting from Westphal et al. (1985): production capability, referring to the numerous capabilities required to operate and maintain production facilities; investment capability, referring to the abilities required for establishing new production facilities and expanding capacity; and innovation capability, referring to abilities to create and carry new technological possibilities through into economic practice. Then, he uses technological capability to indicate the level of organisational capability at a point in time, whereas technological learning is used to depict the dynamic process of acquiring technological capability.

2.3 Technology Transfer

Many firms in the developing countries need to transfer technology in various forms in order to accumulate change-generating technological capabilities.

2.3.1 Definitions of Technology Transfer

In the literature, there have been definitions of 'technology transfer' from different perspectives. As early as 1970, Cooper and Sercovich (p.8) gave a definition for 'mechanisms of transferring technology' as any means for making available to a production enterprise (in a developing country) those elements of technical knowledge which may be unavailable in the domestic economy, required to set up or operate new production facilities. Fransman (1986) defines 'international transfer of technology' as a process whereby knowledge relating to the transformation of inputs into outputs is acquired by entities within a country (i.e. firms, research institutes, etc.) from sources outside that country. Technology transfer is also defined in Rothwell et al.(1988) as the transfer of objective knowledge on its own or with other enabling factors that allow others to add value to their resources. It is not affected by the transfer of information, but by the transfer of know-how.

Bell (1997) quotes from Vaitsos (1974) an analytical definition of the term which emphasises a two-way business transaction: flows of technology running in one direction are matched by the counter-flows of commercial returns sought by the owners of the technology. This two-way direction is very important to mention, because during the policy analysis of the 1960s and 1970s, prescription and practice were less concerned with the technology being transferred to developing countries compared to the 'returns' flowing from them. Attention had focused on the nature and magnitude of these 'costs' being incurred by developing countries in exchange for the technology acquired. Issues related to the first flow mainly concentrated on 'appropriateness' of imported technology for use in the particular economic and social conditions of developing countries (Bell, 1997). Changes took place in international technology policy during the 1980s and 1990s in the direction of liberalisation and deregulation (Radosevic, 1999), thus attention shifted to questions relating to the assimilation of imported technology after it had been acquired, and in particular to questions of dynamic assimilation – its incorporation into a process of technical change and innovation within the importing firms and economies (Bell, 1997). As a result of this tendency, research concentrated on forming frameworks of technology transfer and classifying the channels, considering both the role of the foreign supplier and recipient (Fransman, 1994; Kim, 1999).

As Lall (2001: ix) notes "in its current usage, technology transfer largely refers to movement of commercial technologies across, and to a lesser degree within, countries". This research does not restrict the technology transfer concept to international movement of technologies only, but deals with movement of technologies within the national borders as well.

2.3.2 Dimensions of Technology Transfer Mechanisms

Dimensions of technology transfer such as direct and indirect (Cooper and Sercovitch, 1970; Stewart, 1985), vertical and horizontal (Mansfield, 1975), formal and non-formal (Kim, 1999), externalised and internalised (Lall, 2001), active or passive role of partner (Kim, 1999), embodied and disembodied nature of knowledge (Teece, 1977; Pavitt, 1985; Kim, 1997) have been highlighted and discussed in the literature. These can be useful tools for a classification of technology transfer mechanisms. I will particularly emphasize the distinctions between tacit and codified transfer of knowledge and vertical and horizontal technology transfer, since they are among the most helpful tools for the purpose of this study – i.e. the effect of technology transfer on capability accumulation and emerging firm interactions.

The type of knowledge (*tacit / uncodified* vs. *codified / explicit*) acquired within the process of technology transfer attracted much attention in the literature. The importance of uncodified knowledge in the transfer process has been highlighted (Teece, 1977; Nelson and Winter, 1982; Pavitt, 1985; Kim, 1997; Radosevic, 1999). According to Pavitt (1985: 6) "acquisition of technology is always involved when a firm moves from one vintage of production technique to another, or from one product group to another.

Such acquisition involves not only written information (patents, blueprints, operating instructions), but also person-embodied skills and know-how." Kim (1997a: 87) points out that whereas "explicit knowledge may be acquired in the form of books, technical specifications, and designs or as embodied in machines, tacit knowledge can be acquired only through experience such as observation, imitation and practice; thus tacit knowledge can be transferred only through training or human transfer."

In an earlier paper, Mansfield (1975: 372) emphasizes the direction of links in making the classification. He therefore finds it important to distinguish between *vertical* technology transfer, which occurs when information is transmitted from basic research to applied research, from applied research to development, or from development to production, and *horizontal* technology transfer, which occurs when technology used in one place, organization or context is transferred and used in another place, organization or context. Horizontal technology transfer is mostly used in the international context in the literature, where inter-firm partnerships are explored (Hagedoorn and Schakenraad, 1990). Vertical technology transfer is important for assessing the knowledge flows from a research institute or university, where basic or applied research is conducted, to the industry, where development took place. The importance of university-industry linkages (Nelson and Rosenberg, 1993), the influence of public research on industrial R&D (Senker and Faulkner, 1992; Faulkner and Senker, 1995; Cohen et al., 2002) and universities as sources of innovation for industrial firms (Laursen and Salter, 2004) have been highlighted as important issues and discussed. Vertical technology transfer can also take place between different units in a single firm, e.g. from the R&D unit, where applied research is conducted, to the production unit.

2.3.3 A Taxonomy of Technology Transfer Mechanisms

Based on the dimensions of technology transfer discussed in Section 2.3.2, the sections to follow discuss the classification of the mechanisms of technology transfer, so that the concept might efficiently be used in the later analyses in this thesis.

Table 2.1 Dimensions and types of technology transfer

		Type of knowledge		Direction of interaction	
	Type of technology transfer	**Codified**	**Tacit**	**Vertical**	**horizontal**
Arm's length agreements	Import of machinery and other capital goods	X			X
	Licence agreements, patents and know-how	X			X
	Turnkey agreements	X			X
	Journals, patent disclosures, databases	X			X
	Firm visits, fairs and exhibitions	X			X
	Exporting	X			X
	Subcontracting: Outward processing	X			X
Firm endogenous activity	Reverse engineering		X	X	
	In-house R&D project		X	X	
	In-house problem solving activity		X	X	
Collaborative agreements	Subcontracting: OEM and Direct offset agreements		X		X
	Technical assistance and co-operation		X	X	X
	Strategic technology alliances		X	X	X
FDI	Joint ventures and subsidiaries	X	X		X
	Brain gain		X		X

Source: Mansfield (1975), Pavitt (1985), Kim (1997a), Radosevic (1999: 21).

Figure 2.1 Technology transfer mechanisms by type of knowledge and direction of interaction

Type of knowledge	**Direction of interaction:** Horizontal	Vertical
Codified	Arm's length mechanisms Foreign direct investment	-
Tacit	Collaborative agreements Foreign direct investment	Firm endogenous activities Collaborative agreements

2.3.3.1 Arm's Length Technology Transfer Mechanisms

Arm's length technology transfer mechanisms are associated with a horizontal flow of codified knowledge (see Table 2.1 and Figure 2.1).

Import of Machinery and Other Capital Goods

Import of machinery and other capital goods comes simply by buying machines from foreign sources for the main process lines, for any kind of equipment related to the recipient's core or peripheral activities and related inputs required for the process. It has been considered as one of the most important mechanisms for obtaining technology, since it actually has the largest share by value among all the mechanisms. Simple import of machinery and import of other capital goods such as raw materials is the main channel of technology transfer as embodied in tangibles, especially for the SMEs of developing countries. The significance of import of capital goods lies in the fact that the recipient gets into contact with recent technologies created elsewhere, however the amount of knowledge to be exploited from this activity totally depends on the existence and depth of the recipient's further interactions with the suppliers that it will form as a part of its informal networks. Moreover, the existence, depth and any possible satisfactory exploitation of knowledge spillovers from interactions is highly related to the skills and background of the people in the recipient. Otherwise, the recipient cannot go further than the simple use of the acquired technology, or even sometimes worse, is faced by incapability in its use of the technology.

Licence Agreements, Patents and Know-How

Licence agreements include disembodied technology, generally in the form of product know-how, a patent or intellectual right specified for use of the recipient for a certain period of time, often together with the machinery, equipment, etc. A royalty or a licence fee is paid for use of the intangible acquired. As Stewart (1985) indicates, licence agreements often contain restrictive clauses in relation to the rights of the licensee to export, to conduct and/or use independent research, and tie-in clauses, whereby the licensee has to purchase inputs from the licensor and so on. These restrictions and ties are expected to have negative influences on the improvement of technological capabilities of the recipient firm.

Turnkey Agreements

A turnkey agreement is specified as technology transfer that may include market and feasibility investigation, selection of site and technology, installation and establishment of secondary facilities. It tends to come in the form of establishment of a whole plant for production or extension to the existing production lines.

Journals, Patent Disclosures, Databases, Internet

Scanning of worldwide open scientific and technical literature, information services and data banks are among the important methods of technology acquisition (Freeman and Hagedoorn, 1994). The existence and effectiveness of such an activity in the firm necessitates an established background of skilled people and suitable environment to be able to benefit from the obtained knowledge. Otherwise, in firms without skills, this is a defective method for technology acquisition.

Firm Visits, Fairs, Exhibitions and Conferences

Firm visits, fairs and exhibitions are media for developing country firms to get to know about new technologies and establish informal contacts.

Exporting

Radosevic (1999) mentions the almost overlooked exporting activity as a form of technology acquisition, through a close relationship to foreign buyers. As Porter (1990) noted, fierce competition from rival firms in their own country would motivate firms towards the will and strong desire to improve their technological capabilities by any means (by generally improving their links with the other actors of the system, because the knowledge comes from elsewhere) and would also contribute to the emergence of the innovation system of the country. However, developing countries generally show a lack of fierce competition in their internal markets with the existence of strong rival firms, which would force follower firms to climb through the technology frontier. Given that fact, export activities of the firms in developing countries may be regarded as a substitute for sufficient and strong competition in their own country. However, because of the geographical distance involved, as Lundvall (1992b) points out, knowledge transfer through exporting needs reliable and long-term relationships to be an effective mode of knowledge acquisition.

Subcontracting: Outward Processing (OP)

Subcontracting involves entering into a contract of a main firm (supplier) and a subcontractor firm (recipient) for the manufacture of (not the whole product but) parts, components, assemblies to be incorporated into a product which the main firm will sell to other markets. Therefore, a subcontractor firm is indeed a company that undertakes to complete part of another firm’s contract and subcontracting does not involve any change in the ownership structure of the subcontractor firm. *Outward processing (OP)* refers to a type of subcontracting where temporary exports of goods take place in the subcontractor's country of materials for processing and their subsequent re-importing into the main firm's country being exempt from import or export duties (Radosevic, 1999: 25).

2.3.3.2 Firm-endogenous Activities

Firm-endogenous technology acquisition is identified with a vertical flow of tacit knowledge (see Table 2.1 and Figure 2.1) between differing units within the firm – i.e. from the R&D unit where basic or applied research takes place to the production unit. They are initiated within the firm using largely the firm's own resources.

Reverse Engineering

Reverse engineering is essentially imitation and adaptation of acquired technology without any formal agreement with the original innovator. It involves stripping down innovative products or processes and finding out how they work (Pavitt, 1985). It may involve either a considerable accumulation of technological capability in the recipient as a background or intense interactions with knowledgeable organizations to be able to further the activity. Especially reverse engineering on high process technology needs support beforehand or during the process. In the developing country context, brain gain of people educated and/or with work experience abroad can be a crucial factor in accumulation of technological capability as embodied in people, which is transformed into high technology and science-based reverse engineering activities. Kim (1998) highlights the success and efficiency of reverse-engineering processes in the case of Hyundai Motor in Korea when supported with mobility of skilled labour and heavy investment in R&D.

In-house R&D Project

It has been a common exercise that innovative firms start R&D projects of their own in the firm to produce new products or processes. Although earlier this concept was mostly associated with developed country firms, high and medium technology firms in the developing countries have also increasingly started on such activities. Launching an in-house R&D project certainly depends on the level of technological capabilities achieved in the firm, the key complementary asset being a skilled workforce that is able to carry on the task. It may involve intense interactions with other organizations to be able to further the activity, depending on the capability level of the firm and the disclosure of project details.

In-house Problem Solving Activity

Problem solving activity in a firm is a good measure of firm-level technological capabilities. It may be based on customer feedback or a problem that occurs independently in the firm. In the first case, the producer aims to eliminate the customer's specific problem by bringing original solutions other than recommending its ordinary products/ processes that it delivers. Launching of an R&D activity by the producer is necessary for such an effort to capture and evaluate the changing user needs while it is mostly guided with the feedback from the user. The activity may end up with an incremental innovation on the producer side or it may be the result of previous imitative or innovative activity of the producer.

2.3.3.3 Collaborative Agreements

Collaborative agreement kinds of technology transfer are associated with horizontal or vertical flows of tacit knowledge (see Table 2.1 and Figure 2.1).

Subcontracting: Original Equipment Manufacturing (OEM) and Direct Offset Agreements (DOA)

The outward processing type of subcontracting is defined in Section 2.3.3.1. However, as Radosevic (1999: 25) notes, "subcontracting is a broad term encompassing several types of relationships" at differing depths of interaction and "there is an important distinction between 'normal' subcontracting and *Original Equipment Manufacturing (OEM)* arrangements." OEM is a specific form of subcontracting for production of whole finished products to the precise specification of the foreign contractor, and the contractor then sells the product under its own brand name (Hobday, 1995).

Subcontracting networks may take the form of arm's length contractual relationships (ACR) or obligational contractual relationships (OCR) as analysed in a comparison of Britain's and Japan's lean production systems in Sako (1992). She defines ACR as relationships characterized by an explicit contract that spells out before trading commences each party's tasks and duties, where unforeseen contingencies are settled by resort to some universalistic legal and normative rules. Thus, all dealings are conducted at arm's length, to avoid undue familiarity, with neither party controlled by the other but with a high degree of interdependence. According to Sako (1992: 9-10) OCR, on the other hand, is embedded more in particularistic social relations between trading partners who entertain a sense of mutual trust and goodwill which enables transactions taking place without prior agreement or deviations from the contract to be possible even if the tasks and conditions of each trading partner are negotiated. Outward processing (OP) and Original Equipment Manufacturing (OEM) could be regarded as types of subcontracting activities identified by their strict contractual character and highly formal relations between the partners and, as observed by Sako (1992: 11-12) in the case of arm's length contractual relationships with short-term contract life, low dependence, low risk sharing, low set-up costs, non-negotiated technology relationships and detailed contract clauses. However, as Hobday (1995) observed in East Asian firms, OEM often involves the foreign partner in selection of the capital equipment and the training of managers, engineers and technicians, as well as advice on production, financing and management. Thus, OEM relations allow for horizontal flows of tacit knowledge as well as codified knowledge.

Own Design Manufacturing (ODM) is an expected subsequent step after OEM. Under ODM, firms design and manufacture a range of products with little or no assistance from the main firm (Radosevic, 1999). ODM shows the internalisation of sophisticated design skills of products, and sometimes complex production technologies, on the part of the subcontractor (Hobday, 1995).

Lastly, a special type of subcontracting, which emerged during the fieldwork in Turkey in this study, is worth mentioning. *Direct Offset Agreements*[2] *(DOA)* are a specific form of subcontracting activities for production of either finished product or parts, assemblies

[2] An *Offset Agreement* is a counter contract to a military export sale negotiated separately between the foreign purchaser, usually a foreign government, and the US exporter as a condition of the export sale. The offset agreement requires the US exporter to compensate the foreign purchaser with various types of offsets (DoC, downloaded in 2001b): Offsets may be direct, indirect, or a combination of both. Direct offsets refer to compensation, such as co-production or subcontracting, directly related to the system being exported. Indirect offsets apply to compensation unrelated to the exported item, such as foreign investment or counter trade (DoC, downloaded in 2001a), which is out of the scope of this part of the study.

of products with or without a licence, in strategic industries such as the defence industry, supported by the high-tech industries of the electronics and electric equipment sector, industrial machinery sector and aerospace. They are in the form of a military and commercial service[3] that involves the transfer of technology and know-how, which is provided by US firms to those of other countries (DoC, downloaded in 2001a). There is considerable technology transfer occurring as a result of a direct offset agreement, which may take the form of co-production, subcontracting or licensing activities under direct commercial arrangement between the US manufacturer and a recipient foreign entity, with technical assistance provided to that entity. As a distinguishing advantage, the recipient firm receives most of the time the latest process technology at very cheap prices and moreover has access to crucial high technology know-how, supported by personal training and assistance. Thus, in the long-lasting relationships of successive agreements, the recipient firm can manage to accumulate its own technological capabilities in a very effective way.

Technical Assistance and Co-operation

Technical assistance and co-operation is based on the interactions established by the firm either formally or informally. It can be received from an organization – i.e. a university, research institute or another firm, on a formal contract basis, as well as from an individual person in an informal way with whom the manager of the firm has built a personal relationship. For example, individuals or groups of referees could be charged as consultants to the firm within a sponsored R&D project. Likewise, the recipient can acquire knowledge and training towards better use of the process technology received from the supplier. This is generally a contract basis relationship during which the firm acquires knowledge from the supplier, particularly for the topic of concern. However, its main difference from a strategic alliance is that the acquisition of knowledge is generally a one-way flow of knowledge from knowledge supplier to the firm.

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[3] Historically, offsets have served important foreign policy and national security objectives of the US, such as increasing the industrial capabilities of allied countries, standardizing military equipment, and modernizing allied forces. The use of offsets is now commonplace. Today, virtually all of the defence trading partners of the United States impose some type of offset requirement. Countries require offsets for a variety of reasons: to ease the burden of large defence purchases on their economy, to increase or preserve domestic employment, to obtain desired technology, and to promote targeted industrial sectors (DoC, downloaded in 2001a).

Strategic Technology Alliances: Inter-firm Alliances and Firm-University or Research Institute Partnering

In the current literature, there is no consensus on what exactly a 'strategic alliance' is and what exactly needs to be emphasized in its definition. In a very broad definition, Yoshino (1995) refers to strategic alliances as co-operative business activities formed by two or more independent firms for various strategic purposes. Lorange and Roos (1993) put forward their view on strategic alliances in terms of the *degree of vertical integration*, following the approach of transaction-cost economics, where they take it as a broad concept of the relationship types between markets (free market) and hierarchies (total internalisation or vertical integration) that take the form of mergers and acquisitions (a), joint ownership (b), joint ventures (c), formal cooperative ventures (d) and informal cooperative ventures (e), illustrating a shift from hierarchies to markets in a movement through (a) to (e) with a lessening degree of vertical integration. In an earlier study, Contractor and Lorange (1988) introduced the dimension of *mutual interdependency.* They place importance on the trust and confidence developed between the partners. Lorange and Roos (1993) contribute by stating that a firm might wish to start out in a less committed mode with high interdependence and then upgrade the type of cooperative relationship with low interdependence over time in a movement from (e) to (a). Though equity and trust concepts under market exchange and hierarchical control are touched upon in this approach, targeting a specific goal (such as development of a new product) preferably in a long-term relationship is missing. Hagedoorn and Sedaitis (1998) draw attention to equity and contractual forms of alliances. According to them, based on their study of Russian firms, manufacturing-oriented alliances are more likely to take the joint venture equity form, whereas research-oriented cooperation is geared towards contractual agreements. In my view, manufacturing-oriented alliances apparently aim to be cost-minimizing rather than at a targeted specific goal. Radosevic (1999) prefers to use Dunning's term of 'co-operative alliances', giving the reason that many alliances are not strategic at all but involve spreading network relationships among enterprises. He also points out that alliances are considered to be various forms of company co-operation which are neither arm's length relationships nor mergers and acquisitions; yet, the disagreement among analysts exists whether they involve not only technology or R&D alliances but also production and marketing alliances. At this point, Mytelka's definition appears to be very explanatory and reasonable. Mytelka (1993) defines strategic partnerships as two-way relationships focused on joint knowledge production and sharing, as opposed to one-way knowledge transfer, putting the emphasis on technology and R&D alliances. Narula and Sadowski (2002) restrict them to cooperation types that are more for technological development purposes instead of market exchanges and hierarchical controls. For the purposes of the analysis in this study, I differentiate between marketing alliances and technology, R&D and joint production alliances. Joint production of a new or improved product or process is a natural outcome of a mutual knowledge relationship, which will here be termed strategic technology alliances, based on knowledge sharing but unbound by any type of ownership relations between the partners, keeping them independent of each other. For ease of analysis, strategic technology alliances in this study will be discussed in two different forms as inter-firm alliances and as firm-research institute or university alliances.

Inter-firm Strategic Technology Alliances are partnerships involving a two-way knowledge flow between the parties within the framework of an agreement especially designed for joint R&D for product or process improvement or development. Freeman and Hagedoorn (1994) consider R&D corporations, joint R&D pacts, cross-licensing agreements, research contracts, second sourcing agreements, minority joint ventures and joint ventures with shared R&D resources as means of inter-firm strategic technology partnerships. *Customer-oriented development* may be regarded as a particular form of inter-firm technology alliances between the producer firm and its user/customer firm that inherits greater ambitions than just problem solving. The producer explicitly aims to develop an improved or new product or process in intense collaboration with the qualified, knowledgeable and demanding customer.[4] Advanced country firms are expected to conduct basic and applied research phases of R&D as an in-house activity in such collaboration. On the contrary, developing country firms receive considerable support from other organisations at the stage of basic and applied research. Thus, the activity is supported by other means of technology transfer. The experimental development stage is then realised within the firm. Lundvall (1992b) explains this particular phenomenon of user-producer interaction within the technical change taxonomy of Freeman and Perez (1988), in which geographical and cultural closeness

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[4] For a striking example of customer-oriented development see the ASEA-SKF case history in Hakansson (1987).

plays a big role and where incremental innovation is an on-going activity and radical innovation is a highly likely possibility.

Firm-research institute or university technology partnering happens between a firm from the industry and a research institute (private or governmental or any related university department) on a specific R&D project. There is also the acquisition of knowledge related to basic research findings in this kind of partnership, allowing for a vertical transfer of technology.

2.3.3.4 Foreign Direct Investment

Foreign direct investment is associated with a horizontal flow of codified and tacit knowledge (see Table 2.1 and Figure 2.1).

Subsidiaries and Majority Joint Ventures

Foreign Direct Investments (FDI) are those that are made outside the home country of the investor, but inside the investing company; thus the control over use of resources transferred remains with the investor, giving it an effective voice in the management of the foreign firm (Radosevic, 1999: 20). The investor going through FDI has to decide on the entry mode choice, that is between a wholly-owned subsidiary and a majority joint venture; however the technological intensity of the industry in which FDI takes place has been said to discourage joint ventures in favour of wholly-owned subsidiaries (Mutinelli and Piscitello, 1998), partly because the vast majority of foreign companies also prefer to bring in their own process technology and knowledge to their own subsidiaries under their total control, and thus the knowledge transfer takes a one-way shape.

Joint venture is indeed one of the types of formal networks as a kind of equity-oriented strategic alliance among firms. Two or more firms join forces under a group or by establishing another firm for various reasons. Hagedoorn (1993) mentions that joint ventures focus on a wide range of company activities aiming at development through manufacturing and marketing within the value chain of company activities. At that point, joint ventures are treated more like manufacturing-oriented international alliances (in Hagedoorn and Sedaitis, 1998). On the other hand, von Tunzelmann (1997) points to the knowledge exchange/ knowledge seeking dimension in joint ventures saying that before 1970s, they were typically "one-directional", e.g. one of the firms with high-technology knowledge seeking market access in other markets, whereas with the greater equalization of technological abilities among North American, Western European and East Asian firms, they became increasingly "bi-directional", involving mutual exchanges of both know-how and markets, seeking complementarities. Yet, most of the developing country firms seek joint venture possibilities with technologically stronger western firms with the main aim of benefiting from their high-technology knowledge and available finance while being able to offer only market access through one-directional means. Because a majority joint venture as an inter-firm collaboration involves an ownership relation, it is regarded as a different technology transfer mechanism from strategic technology alliances in this study. However, a possible knowledge exchange relationship is always a matter of debate in minority joint ventures with shared R&D resources.

FDIs are mostly paired with multinational companies in the existing literature, since most of the traditional FDIs come from large companies in the form of a package of technology. Currently, spillovers from FDIs have been subject to debate in the literature for their possible contribution to improvement of indigenous technological capabilities. Under the effects of financial globalization, FDI expanded much more rapidly than trade during the 1980s, and on balance followed a Myrdalian pattern of flowing much faster to the world's financial centres than to the needier parts, e.g. the USA was the major beneficiary of net inflows of capital during the 1980s (von Tunzelmann, 1997).

Brain Gain (and Brain Re-gain)

'The Brain Drain' is an emotional term which suggests that the creative intellectual strength of the country is draining slowly but surely away through the emigration of qualified engineers, technologists and scientists (Working Group on Migration, 1967:1) from their home countries to advanced countries. The opposite occurrence is called 'The Brain Gain'. And 'Brain Re-gain' includes the return home (to home universities or firms) of postgraduate students and faculty sent to advanced countries for education, training and experience.

A firm's possession of skilled personnel with new knowledge from abroad is a valuable vehicle for the transfer of tacit knowledge. However, this is generally put into the same category (transferring technology by people) as firm visits and exchanges by Radosevic (1999: 26). I consider that the person-embodied knowledge that comes from outside the country (from an advanced country) to stay for long periods inside the country (the developing country) is significantly different from the knowledge acquired by mobility of people in firm visits, exchanges or training. The claim here is that the foreign-acquired, person-embodied tacit knowledge may be regarded as an equivalent of the acquisition of codified and tacit knowledge from advanced country foreign firms directly investing in the developing country.

Attracting researchers, engineers and students, especially those educated and with work experience abroad related to their fields and maybe having started their own SME in the home country, is a very effective means of technology transfer, particularly in science-based industries, which contributes immensely to the accumulation of technological capabilities at the firm and sectoral level. These qualified people come over with their already established links spanning international borders, which promote mutual knowledge exchange and thereby bring a different approach and new dynamism for research to the traditional methods in the developing country. Kim (1997a, 1998) provides empirical evidence based on case studies of Samsung and Hyundai Motor for the significance of knowledge gained from new scientists and engineers recruited from the US. Sometimes government-initiated programmes prove to be successful in recruiting engineers and scientists from abroad for particular R&D projects for longer than six-month periods (Kim, 1997: 67).

2.4 Relating Technology Transfer to Technological Capability Accumulation in the Firm

Technology transfer is a channel facilitating development, improvement and strengthening of technological capabilities in the latecomer firms, as Kim (1999) argues, through its contribution to the existing knowledge base of the firm. Moreover, the choice, or mode, of technology transfer is a function of the attributes of the technology, as well as attributes of the technology receiving firm or industry (Contractor, 1998: 321). Domestic firms are crucial agents of the transfer process, and how they complement foreign sources with their own technology effort can be decisive in the effectiveness of technology transfer (Radosevic, 1999).

Technological capability accumulation in a developing country firm is always considered to be associated with the inflow of knowledge to the firm from outside sources, along with firm-internal efforts. Knowledge inflow from outside sources occurs basically by means of transfer of technology from advanced country firms or other institutions either foreign or domestic.[5] Yet, *what kind* of knowledge comes is as important as *how* the knowledge comes for capability accumulation. It is rather the former that determines the degree of capability accumulation (in a scale from basic to advanced). Lee and von Tunzelmann (2005: 433) state that “science and technology transfer comes in two ways: by technology transfer out of universities and institutes (public or semi-public) into commercial use, and from overseas to domestic use. There are several ways to absorb alien technologies (spin-off, joint venture, alliance, licensing, purchase of technology, turnkey, etc.). For an infant industry, it is necessary to purchase new technology in order to catch up developed countries’ technology capacity and achieve any possibility of ‘leapfrog’. Thus the kind of approach to transfer and the extent to which content is transferred are important”.

So, in dealing with technological capability accumulation, one needs to identify three dimensions:
(i) means of technological capability accumulation (via technology transfer channels),
(ii) degree of technological capability accumulation (absorptive capacity), and
(iii) source of technological capability accumulation (domestic, foreign, firm-internal).

2.4.1 Does the Technology Transfer Mode Matter?

This thesis intends to test whether the mode of technology transfer is influential on technological capability accumulation or not. For this reason the ‘mode of technology

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[5] Sources of knowledge are discussed within the ‘innovation systems’ concept where an organizational structure exists among the institutional bodies. Studies from advanced country experiences have shown that an organized system provides a good habitat for effective accumulation of technological capabilities and innovation. This is also valid for newly industrialized countries like Korea, Taiwan, etc., as is explained in section 2.5 of this chapter.

transfer' variable[6] is used in the further analyses in Chapter 5.

As Radosevic (1999: 85) points out, technological capability research has been much less concerned with the process of their kind of acquisition, basically giving information on 'what' but not 'how'. Whether the mode of transfer is an important attribute of the technology transfer process or not is a frequently asked question. Researchers have different views on the importance of channels of technology transfer. Radosevic (1999: 140-5) groups them in three: (i) transfer channels do matter, (ii) they are of secondary importance and (iii) they are industry specific.

2.4.1.1 The Transfer Mode Does Matter

In the 1960s and 70s, technology transfer policies, especially for the developing countries, were shaped by a mainstream approach framed in an environment of import-substitution development policies in the developing countries. This approach emphasized the appropriateness of the transferred technology into a developing country and argued that only such appropriate technology, meaning the level of technology-acquired need to be compatible with the absorption level of the country, could be acquired with favourable results for the recipient country. Such an argument implicitly supposes that the channel of transfer does matter from the point of view of technological capability improvement in the country. Lall (2001: xii) states that, "the mode of technology transfer can have important effects on the nature and pace of indigenous capability development", putting the emphasis on internalised modes of transfer compared to externalised modes – i.e. FDI. Hoffman and Girvan (1990: 47-8) distinguish different mechanisms of technology transfer according to ownership, implying that the mechanisms that involve less foreign ownership afforded better opportunities to acquire technology at reasonable costs. Thus, they mentioned the preference for joint ventures over wholly owned subsidiaries; licence agreements over joint ventures; direct purchases of equipment from machinery suppliers over joint ventures, and so on. Radosevic (1999: 140) also points to the hierarchy of channels from a host country perspective according to the cost criterion, being licences in the first place and then followed by turnkey plants, capital goods imports, joint ventures and

[6] Details about this variable and the basis as to how technology acquisition channels are classified is provided in Section 2.3 of this chapter.

FDI. Contractor (1985), Ernst and O'Connor (1990), Pack and Kamal (1997) and Lall (2001) have supporting views on the important implications of the method of transfer for technological and economic development of host countries and their firms.

2.4.1.2 The Transfer Modes are of Secondary Importance

This claim is based mainly on the argument that the implementation ability in the transfer process is crucial, that is it is more about how the method is implemented, at the micro level, rather than the method of transfer itself, as discussed in Dahlman et al. (1987). This view puts the emphasis on more important factors such as 'absorptive capacity' of the firm or country in the first place, ahead of the mode of technology transfer.

2.4.1.3 The Transfer Modes are Industry Specific

This view concentrates on industry-specific characteristics of transfer channels. Pavitt (1985) and Bell and Pavitt (1993) show the industry-specific nature of channels in Pavitt's taxonomy of innovations (Radosevic, 1999: 143). Drawing on a wide range of empirical evidence from developed, developing and centrally planned economies, Bell and Pavitt (1993: 177-82) differentiate between five categories of firm types, namely supplier-dominated, scale intensive, information intensive, science-based and specialized-supplier. They find that the main channels of imitation and technology transfer are purchase of equipment and related services for supplier-dominated firms; purchase of equipment, know-how licensing and related training and reverse engineering in scale-intensive firms; purchase of equipment and software and reverse engineering in information-intensive firms; reverse engineering, R&D and hiring experienced engineers and scientists in science-based firms; and finally reverse engineering and learning from advanced users in specialized-supplier firms.

2.4.2 Absorptive Capacity: Existing Knowledge Base and Intensity of Effort in the Firm

Firms need to be able to absorb the transferred technology, in whatever form they acquired it, in order to make use of it. In the technology transfer literature, especially after the 1980s and 1990s, attention was mainly devoted to questions relating to the assimilation of imported technology after it had been acquired, and in particular to questions of dynamic assimilation – its incorporation into a process of technical change and innovation within the acquiring firms and economies (Bell, 1997).

As Mowery and Oxley (1997:140) cite from Cohen and Levinthal (1990), the exploitation of externally acquired technology requires the creation of some ‘absorptive capacity’ within the firm. Cohen and Levinthal (1990) label the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends as the firm’s absorptive capacity, and they suggest that it is largely a function of the firm’s level of prior related knowledge. Kim (1997, 1998) elaborates more on Cohen and Levinthal’s (1990) absorptive capacity, in forming a framework for the concept that has as its dimensions *intensity of effort* and *existing knowledge base*, which are determinants of technology acquisition process, to drive incremental increases in the resultant capabilities of the firm. In these studies, only firm-related factors that influence, improve and strengthen the accumulation of technological capabilities are considered. As Kim (1997: 97) explains in his framework for the dynamics of technological learning, existing tacit knowledge influences the learning process today and the nature of learning tomorrow. Kim also points out that the second important element is intensity of effort or commitment in the firm. It is insufficient merely to expose individuals and firms to explicit knowledge. Without conscious efforts on the part of individuals in a firm to internalise such knowledge, learning cannot take place. At the micro level, *existing knowledge base* and *intensity of effort* would be the two essential elements of a technology acquisition process for the technological capability build-up of the firm.

Studying the case of Hyundai Motor, Kim (1998) elaborates deeply on the determinants of existing capabilities (prior knowledge base) and intensity of effort in the firm. In his framework, tacit knowledge is at the core of the prior knowledge base. The firm may have some proprietary explicit knowledge such as firm-specific blueprints and standard operating procedures. However, they are useful only when tacit knowledge enables its members to utilize them (p.159). Therefore, the firm’s existing capabilities are mostly embodied in the workforce of the firm, mainly the managers, researchers and engineers. Kim (1998:160) also points out that entrepreneurial leadership is an important factor that creates organizational conditions conducive to learning. This research utilises the manager's qualifications and percentage of researchers and engineers in the firm as variables to define the existing capabilities of the firm.

In Kim's framework, the aim of intensity of effort is to elevate the level of absorptive capacity of the firm by giving impetus to its prior knowledge base. Intensity of effort is comprised of several elements. As Kim (1998:164) observed in Hyundai Motor, at the outset of each learning jump, it took preparatory measures to elevate its knowledge base. Those measures included poaching of experienced personnel from outside, extensive literature searches, observations of technology in operation, and temporary hiring of foreign engineers. Putting effort into the acquisition of prior knowledge through literature reviews and poaching new personnel from outside may be very effective for identifying and acquiring technology available elsewhere and facilitating learning in the subsequent phases. Mobile experienced personnel in particular have been a major source of new tacit knowledge (Kim, 1998:168). Complementary to those efforts, Hyundai invested in R&D sharply, in amounts measured in billions of US dollars. Its engineers underwent hundreds of trials for their own original design of new prototype engines until eventually the engine outperformed its Japanese rival in all tests (Kim, 1998:166-67). Largely drawn from Kim's observations in Hyundai Motor, the search into technology to be acquired and into the suppliers of technology prior to the acquisition process, the type and level of R&D activities and the existence and level of design activities in the firm are used as variables in this research to define its intensity of effort.

2.4.3 Levels of Technological Capability Accumulation

Technological capability accumulation is studied at different levels in the literature – i.e. firm level, industry level, or country level. Kim (1999) presents an analytical framework at the firm level to study technological capability accumulation based on evidence from the Korean experience. At the heart of these frameworks lies 'absorptive capacity', which is supported by both firm-related and governmental factors that influence, improve and strengthen the formation of technological capabilities at mature, intermediate and emerging technological stages (see Table 2.2).

Table 2.2 Elements of Kim's Absorptive Capacity Framework based on observations from Korean industries

	Mature Technology Stage	**Intermediate Technology Stage**	**Emerging Technology Stage**
Existing Knowledge Base	*education * foreign technology transfer * mobility of experienced technical people	* formal technology transfer * reverse brain drain * corporate R&D * universities and government research institutes (GRIs)	* basic research in universities * mission-oriented applied research at GRIs * intensity of corporate R&D activities * globalisation of R&D recruitment of high calibre personnel from abroad
Intensity of Effort	* export promotion * hasty creation of heavy and chemical industries * technology transfer strategy * crisis construction	* degree of market competition	* increasingly heightening market competition

Source: Kim (1999).

Inspired by Utterback and Abernathy's (1975) technology trajectory framework for advanced countries following three stages (fluid-transition-specific), Kim (1999: 113-4) postulates also three stages (emerging-intermediate-mature technology stages) for developing countries. Yet, as also put forward by Hobday (1995), Kim (1999: 115) concludes that developing countries reverse the direction of the technology trajectory argued by Utterback and Abernathy in advanced countries and evolve from the mature technology stage (for duplicative imitation), to the intermediate technology stage (for creative imitation), and to the emerging technology stage (for innovation). This follows the route from acquisition to assimilation and then to improvement.

Because developing country firms are largely dependent on importation of production processes, technological capability accumulation in the first place starts with the acquisition of these kinds of technologies. Von Tunzelmann (1997) also refers to indigenous technological capabilities (ITCs) as the cornerstone of industrial advance, with the aims of minimizing foreign control as quickly as possible and generating export competitiveness. Drawing from Katz (1985) and Westphal et al. (1985) on their observations from Latin American countries, he identifies three levels of ITCs: "Countries first need to be able to *operate* plants and equipment that others had built within them; second to be able to *invest* in and construct new plants and equipment of their own; third to be able to improve them and *innovate* new designs of plant and equipment" (von Tunzelmann, 1997: 363). He calls this process *indigenization*. The route explained here for technological capability accumulation is similar to Kim's (1999) acquisition-assimilation-improvement trajectory observed in Korea.

A comprehensive classification for each level of technological capability accumulation was presented in Bell (1997: 69). He dealt with the distinctions between different *degrees of assimilation* from imported technology effortlessly binding the concepts of technology transfer and technological capability accumulation. He categorized these distinctions as below:

(1) *Operational assimilation:* the acquisition of technology in the form of designs, specifications, equipment and so forth, together with the skills and know-how needed to use and operate the technology at its design levels of performance.

(2) *Replicative assimilation:* going beyond the static use of given technologies and acquiring or developing knowledge and capabilities needed to reproduce (elements of) the technology – either for repeated investment in similar facilities or in order to diffuse specifications and know-how to local suppliers of materials, components, sub-assemblies and so forth.

(3) *Adaptive assimilation:* going beyond replication to acquire or develop capabilities needed for incremental adaptation, improvement and re-design of the initially acquired products, processes and product organization.

(4) *Innovative assimilation:* developing and acquiring knowledge and capabilities needed to make more substantial developments in the technology, such as are incorporated in new 'generations' or 'vintages' of a product or process.

Lall (1992:166-9), drawing on the empirical works of Katz (1984, 1987), Dahlman, Ross-Larson and Westphal (1987) and Lall (1987), categorizes firm-level technological capabilities under three major functional groups as investment capabilities, production capabilities and linkage capabilities, in which the knowledge, skills and experience embodied in human beings are predominantly emphasised. In an illustrative two-dimensional matrix, he matches the degree of complexity of technological capability (basic-simple, routine-experience based; intermediate-adaptive, duplicative-search based; advanced-innovative, risky-research based) with the functions of technological capability (investment, production, linkage). *Investment capabilities* are the skills needed to identify, prepare, obtain technology for, design, construct, equip, staff and commission a new facility (or expansion). *Production capabilities* range from basic skills such as quality control, operation and maintenance, to more advanced ones such as adaptation, improvement or equipment stretching, to the most demanding ones of research, design and innovation. Finally, *linkage capabilities* are the skills needed to transmit information, skills and technology to and receive them from raw material suppliers, subcontractors, consultants, service firms and institutions. He matches functional activities of the firm with the degree of complexity of each activity, as how the matrix is filled in. He states that “the degree of complexity is measured by the sort of activity from which the technological capability arises”. The categorization of technological capabilities in Lall’s (1992: 168) illustrative matrix, as he points out, “is necessarily indicative, since it may be difficult to judge *a priori* whether a particular function is simple or complex”. Also, it does not show any sequence of learning from simpler to more difficult activities as proposed in Dahlman, Ross-Larson and Westphal (1987). This study uses Lall’s (1992) categorization of technological capability assimilation in developing countries, because it provides a simple but comprehensive context for levels of capability assimilation.

2.5 Systems of Innovation

This research continues with the second research question of “How do the increments in technological capabilities from technology transfer process influence the emergence and the elements of the system of innovation in the materials industry in Turkey?” The sections to follow aim to locate the concepts in this question in the related literature.

2.5.1 The ‘System’, its Elements and Definitions

The ‘system’ itself implicitly includes ‘order’. Therefore, an orderly relation is expected among the elements of any ‘system’. There have been varying approaches to the innovation systems notion defined in the literature. Each of them has their very tidy order in itself, but the definitions of the ‘system’ as a whole and the constituents of the systems differ profoundly, and thus the concept becomes confusing. On the other hand, as Edquist (1997) mentions, different approaches of innovation systems may be useful for various purposes or objects of study.

The most substantial issue is to ascertain the borders of the system as a whole. In other words it is necessary to identify more conclusively what elements are in the system and what elements are outside it. Recent approaches to system analysis differ in identifying their borders, if not at least their core elements. Secondly, the type of relations and the directions of causality between the elements of the system are of vital importance.

The firm, having organic ties with the production system, lies at the core of all types of systems, either as itself as an agent or in the form of a function of innovation, interactive learning or technology, and builds the connection between the production system and the innovation system. By extension, inter-firm relations and core capabilities of the firms come to be the activating and stimulating factors in the development of innovations. Innovation systems are implicitly firm-centred in that sense.

Other than the firm, ‘institutions’ are elements of the ‘system’ that could not be neglected or handled entirely outside its boundaries. However, as Edquist (1997) mentions, the term ‘institution’ is used in two main senses in the literature: (i) ‘formal structures with an explicit purpose’ or what are normally called organisations as described in Nelson and Rosenberg (1993), and (ii) ‘things that pattern behaviour’ like norms, rules and laws as described in Lundvall (1992). It may also become a combination of both former meanings: “both rules and laws determining behaviour and organisational structures in the concept of institutional infrastructure”, as Carlsson and Stankiewicz (1995) note. Organisations in the ‘institution’ concept are represented by the universities, national and private research institutes, which pursue R&D activities. The networks through which they interact and the changes in the type, breadth and depth of these networks over time are examined in slightly different system definitions throughout the literature.

“Innovation systems are usually defined by the volume and characteristics of the linkages that bind them together” (Archibugi et al., 1999: 531). The volume of interactions is important in a system in order to characterise whether it is a dynamic and vibrant or a static and inert system. An innovation system is dynamic with positive feedback and reproduction and it is social as well, because learning is a social activity, which involves interaction between people.

There are several different approaches in the existing literature attempting to form an analytical framework to pave the way for in-depth analysis of innovation systems. The selected characteristics of the approaches are summarized in Table 2.3 as explanatory in relation to the following sections.

2.5.2 National Systems of Innovation (NSI)

Freeman (1997:24) signifies Lundvall as the first user of the expression ‘National Innovation Systems’. Besides that, with a historical perspective he observes that the idea of a national system was first introduced by Friedrich List in his conception of the ‘National System of Political Economy’ in 1841, in which he was concerned about underdeveloped countries’ industrialisation and growth as a result of a range of policies applied, in the example of Germany overtaking England. At the OECD level, the concept was given a prominent place in the outcome of the Technology/Economy Programme in 1988, an effort to understand the importance of technology for economic change as Lundvall (1992) notes.

Table 2.3 Specifying characteristics of the Innovation Systems

	National Innovation Systems	Technological Systems	Sectoral Innovation Systems
Unit of analysis	innovation=interactive learning =*f* (economic structure, firm strategy)	technology + industry	firms within a certain sector, with a common range of products
Process of innovation	path-dependent, incremental innovative activities: creation of new technology on the national basis	generation, diffusion and utilisation of technology: economic competence + networks	increasing cumulativeness of technological knowledge over time as sectors become more concentrated and firms accumulate capabilities and resources.
Performance of innovation	creation of new technology	density of technological interactions of firms	technology development through processes of interaction and cooperation
Boundaries of the system	national borders = many technological systems (TS defenders' view)	a specific technology area where the density of interactions is important (region, industry, etc.)	sectoral boundaries: different industries (in product terms) may have different competitive, interactive and organisational boundaries
Elements of the system	*internal organisation of firms *inter-firm relationships *role of the public sector *institutional set-up of the financial sector *R&D intensity and R&D organisation	*firm (economic competence) *networks (to which firms belong) *institutions (universities, etc.) *bridging institutions (industrial associations)	*private firms *fundamental research organisations like university departments and national research laboratories *government policies *specific properties of technologies
Characteristics of the system	**dynamic:** positive feedback and reproduction **social:** because learning is a social activity which involves interaction between people	**dynamic:** networks --> development blocs (synergistic clusters of firms and technologies within an industry or group of industries) (causation appears in the presence of entrepreneurs and critical mass)	relatively homogeneous sectors but quite articulated and dynamic processes of competition and selection acting upon firms and products.
Influencers of the system	*national education and training system *historical experience *language *culture	*government: public policy *cultural circumstances *linguistic circumstances *other (which facilitate or impede contacts among units within the system)	technological regime (TR) broadly defined by four fundamental factors: *opportunity conditions *appropriability conditions *cumulativeness and technological knowledge *nature of the relevant knowledge base

Source: Drawn from frameworks available in Freeman (1987), Lundvall (1992), Nelson (1993), Breschi and Malerba (1997), Carlsson and Jacobsson (1997), Carlsson (1994), Malerba (2004).

However, in an early study on Japan, Freeman (1987: 1) defines the NSI as “the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies”. He (1987: 4) distinguishes the four major elements of the Japanese national innovation system as: the role of company R&D, implying the internal organisation of the firm; the role of the Ministry of International Trade and Industry (MITI), denoting the role of public sector; the role of education, training and related social innovations; and finally the conglomerate structure of industry representing the national economic infrastructure. In this way, he locates a heterogeneous set of interactions in broad boundaries drawn by national factors. His understanding of the national innovation system concept is based on the fact that “historically there have been major differences between countries in the ways they have organised and sustained the development, introduction, improvement and diffusion of new products and processes within their national economies” (Freeman, 1997: 42). As complementary to that, Freeman (1997: 29-30) remains critical about a large volume of studies by OECD on countries’ technological indicators, which are mainly driven by R&D measures as the source of innovation. Standardized by the Frascati Manual (OECD 1963), this approach dominated the research first in developed and then the developing countries. Even though R&D is a strong indicator of innovation in the firms, there are certainly other important factors influencing technical change – i.e. “education, training, production engineering, design, quality control, etc.” (Freeman, 1997: 30). Moreover, these factors need to be framed by strong network linkages as opposed to “weak or non-existent linkages between marketing, production and procurement”, as Freeman (1997: 33) shows in contrasting examples of the successful Japanese national innovation system and the failed Soviet Union innovation system in the 1970s.

Lundvall (1992a) spells out the NSI as all parts and aspects of the economic structure and the institutional set-up (firm strategy) affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place. The internal organisation of the firms, inter-firm relationships with particular emphasis on user-producer relations, the role of the public sector, the institutional set-up of the financial sector and R&D intensity and organisation are the elements within the boundaries of the system. Lundvall’s (1992) study, conducted by a group of economists from the IKE Group at Aalborg University through more than a decade, aims to provide an analytical and theoretical basis for the NSI concept, by locating ‘interactive learning’ and ‘innovation’ at the core of the *social* and *dynamic* system, which captures intense interactions by learning-by-interacting among the institutions as external to the firm and also the firm’s own intensity of efforts by learning-by-doing and learning-by-using as internal to it.

According to Nelson (1993), a country’s NSI comprises the network of public and private institutions that fund and perform R&D, translate the results of R&D into commercial innovations and affect the diffusion of new technologies. Nelson (1993a) illustrates the elements of the system as the industrial research laboratories, universities, interactions between upstream and downstream firms, component and systems producers, and industry and government agencies. He also strongly believes that the national education and training system, the circumstances of competition for firms, the package of fiscal, monetary and trade policies determined by the responsible governments, the historical experience of the nation, its language and culture have a substantial influence in shaping the system. In addition to those, demand conditions and the size of internal market, the country’s factor endowments, the existence of sufficient and strong competition within the country and strong national links that are industry and/or product specific are also important in shaping its innovation system.

Nelson (1993) draws a complete picture of the whole national status derived from sectoral or industrial evidence for each country, without tackling specific case studies. Despite that, the unit of analysis in the NSI studies of Lundvall (1992), as theoretically complementary to Nelson’s work, is the innovation or interactive learning as its equivalent, which is a function of economic structure and firm strategy. Therefore, the firm itself occupies an important place as an ‘institution’ in the broad NSI context.

Porter (1990) analyses the national competitive advantage of nations at the industry (meso) level within a conceptual framework determined by firm strategy, structure and rivalry, factor conditions, demand conditions, and related and supporting industries, from which he derives conclusions for the national system. In his introduction added to his 1990 book in 1998 (p.xxi), he stresses that his focus is on the microeconomic foundations and he seeks to highlight the role played by companies. The problem with Porter’s analysis is, as Lundvall (1992a) also draws attention to in the footnotes (p.19), that it is unclear how he moves from the analyses of cases at the industry level to his conclusions at the national system level, and there is no apparent firm-level case study in his book to prove his focus on the microeconomic foundations. Porter's book remains a good reference for specific industry-based case studies in certain countries.

In all those definitions it is important that all these activities are either located within or rooted inside the borders of a nation state (Lundvall, 1992a). As a result, the NSI comes out as a concept that links institutions at the *national level* to the technological performance of a country. Freeman's (1987), Lundvall's (1992) and Nelson's (1988, 1993) studies are complementary to one another, with Freeman shedding light on the realities of the Japanese national innovation system, Lundvall proposing a theoretical basis based on observations from Scandinavian countries and Nelson presenting valuable country-level evidence from industrialised large and small countries as well as some developing countries.

2.5.3 Technological Systems Approach

Technological systems are networks of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of technology (Carlsson and Stankiewicz, 1995). They are defined in terms of knowledge or competence of flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks (Carlsson and Jacobsson, 1997). 'The particular institutional infrastructure' comprises normative structures and regimes as well as organizations of various kinds, increasing the degree of complexity for understanding the approach (Edquist, 1997).

Substantial elements of the Technological Systems approach arise as the firms (economic competence: the ability to identify, expand and exploit business opportunities), networks (to which firms belong), institutions (research centres, universities, etc.) and bridging institutions (organizations which establish and maintain interaction among various actors in the system) are all located within the boundaries of technological systems (Carlsson, 1994). The effective organisation of production and distribution of knowledge and competence is by far the most intricate institutional issue related to the promotion of technological change (Carlsson and Stankiewicz, 1995).

Government policies, cultural and linguistic circumstances are kept outside the boundaries, though they are given importance as factors affecting the system. The firm is placed at the very core of the concept as it tends to place more emphasis on the microeconomic aspects of technology utilisation, diffusion and generation. The creation of new technology pushes out the production possibility frontier. But it cannot be simply assumed just that because a technology exists, it is also known and used effectively. Unless the expanded set is converted into economic activity, it has no impact (Carlsson, 1994). This is where the concept of 'economic competence' comes in. Carlsson (1994) distinguishes four components of 'economic competence' that are all related to firm-level capabilities: selective (strategic) capability, i.e. the ability to make innovative choices of markets, products, technologies, key personnel; organisational (integrative, coordinating) capability, i.e. the ability to organise the business in such a way that there is greater value in the corporate entity as a whole than in the sum of the individual parts; technical (functional) capability, i.e. the ability relating to various functions in the firm such as production, engineering and R&D; and learning ability, i.e. the shaping of a corporate culture which encourages continual change in response to changes in the environment. These measures are all closely related to putting the firm at the very core of the concept.

The Technological Systems approach has substantial differences from that of National Innovation Systems. The boundaries of the former are drawn by technological rather than national boundaries; they vary in character and extent from one technology area to another within any country; and finally, the diffusion and utilization of new technology also takes place besides its creation as considered in the NSI (Carlsson, 1994). The technology area referred to might be a region, an industry, or other category where the density of interactions is important compared to the boundaries.

The approach has been derived from case studies of Swedish factory automation, electronics, pharmaceuticals and powder technology industries (Carlsson, 1994). There are also studies of Russian manufacturing industry.

2.5.4 Sectoral Innovation Systems (SIS)

The Sectoral Innovation Systems (SIS) approach, introduced initially by Breschi and Malerba (1997) and in a recent work developed substantially by Malerba (2004), might actually be considered as a derivative of technological systems approach, where the boundaries are those of the industry and the private firm is placed at the core. Research institutions, government policies and specific properties of technologies are not ignored totally and supposed to be elements of the system, while a Technological Regime (TR) concept is brought in, dating back to Nelson and Winter (1982) and Breschi and Malerba (1997), symbolising the specific features of the relevant technologies and accounting for the dynamics of SIS and shaping its spatial boundaries. Breschi and Malerba (1997: 152) define the SIS as “system (group) of firms active in developing and making a sector’s products and in generating and utilizing a sector’s technologies; such a system of firms is related in two different ways: through processes of interaction and cooperation and through processes of competition in innovative and market activities.”

Breschi and Malerba (1997), however, discuss the SIS as located within four dimensions from technological point of view by a Schumpeterian dynamics approach. They (p.133) borrow the *opportunity* conditions and *appropriability* of conditions from Nelson and Winter (1982), which have major effects on intensity of innovation, degree of industrial concentration and the rate of entry in an industry; and add to these the *cumulativeness* of technological knowledge and nature of the *knowledge base* to define the notion of a Technological Regime. They believe that these variables appear to be the most relevant factors affecting the dynamics of market structure and innovation, maybe more than firm size or demand. They define opportunity conditions as reflecting the likelihood of innovating for any given amount of money invested in search (p.134). Appropriability conditions summarize the possibilities of protecting innovations from imitation and reaping profits from innovative activities (p.135). Cumulativeness denotes an economic environment characterized by relevant continuities in innovative activities (p.135). Finally, the nature of the knowledge base is determined by dimensions such as generic vs specific, degree of tacitness, degree of complexity, degree of independence and the means of transmission and communication (p.136). As Johnson (1997: 40) notes by taking technological regimes as the basis for the SIS, Breschi and Malerba put much more of the burden of explanation on the above explained technological factors and much less on institutional factors; nevertheless they do not deny the major role played by institutions in the development of all systems of innovation, including the SIS.

The SIS initially has been tested empirically, as based on patent data, on five sectoral innovation systems, namely traditional sectors, mechanical industries, the auto industry, computer mainframe industry, software and microelectronics industry. The empirical results have been exhibited on selected dimensions of the SIS for six industrialised countries, USA, Japan, Germany, France, UK and Italy. The results confirm that both country-specific and technology-specific factors affect in essential ways the sectoral as well as the spatial organization of innovative activities within given industries (p.153). Nevertheless, one can always discuss the drawbacks of the use of patent statistics in capturing the effects of very complex qualitative dimensions of their study.

In a recent work based on Malerba and Orsenigo (1996, 1997) and Breschi and Malerba (1997), Malerba (2004) provides a more comprehensive framework for the sectoral innovation system approach. It is based on the fact that knowledge, technologies and interactions change over time and differ among different industries. In this framework, the boundaries of the innovation system are clearly defined by a particular sector, which "is a set of activities that are unified by some related product group for a given or emerging demand and that share some basic knowledge" (pp.9-10). He does not separate production activity from the system of innovation and thus the system is a broad concept "composed of a set of agents carrying out market and non-market interactions for creation, production and sale of sectoral products" (p.10). He also states that "systems have a knowledge base, technologies, inputs and demand", where "the agents are individuals and organizations with specific learning processes, competencies, organizational structure, beliefs, objectives and behaviours interacting through processes of communication, exchange, cooperation, competition and command, and whose interactions are shaped by institutions" that include "norms, routines, common habits, established practices, rules, laws, standards and so on" (pp.10, 16 and 18). These definitions suggest that a sectoral system encompasses "three building blocks – i.e. knowledge and technology, actors and networks, institutions" (p.10).

By locating the knowledge base at the centre of the framework, Malerba (2004) incorporates firm-level learning and technological capability accumulation in the firm into the analysis of the system. The accessibility of knowledge – both internal to the sector (mainly via inter-firm interactions) and external to the sector (mainly via universities or research laboratories), technological opportunities either created in the universities or in R&D by firms, as well as the cumulativeness of knowledge via learning processes, firm-specific capabilities and feedback from the market are substantial aspects of the knowledge acquisition process in Malerba's sectoral innovation system framework. In addition to the above, Malerba (2004: 21) also draws attention to the appropriability of innovations, which "relates to the possibility of protecting innovations from imitation".

The sectoral innovation system approach regards "innovating, producing or selling firms as the key actors" in the system (Malerba, 2004: 24). User (von Hippel, 1988) and supplier firms are not excluded from this category. The important role of the latter as sources of knowledge in close relationships with the firms is emphasized. The degree and the role of such relationships differ in different sectors. Malerba (2004: 25) groups universities, financial organizations, government agencies, local authorities, etc., under non-firm organizations, which are supportive of innovation and technological diffusion and states that their role also differs in different sectors.

2.5.5 Network Alignment Approach

The network alignment approach (Kim and von Tunzelmann, 1998; Lee and von Tunzelmann, 2005) amalgamates the approaches of political governance scholars and the perspectives of the national, technological and sectoral innovation systems approaches by putting much of the emphasis on the role of the state. The alignment concept, which is a more comprehensive structure to explain networks, is used to explain the specific connections between the demand-side global networks, a supply-side national network and the role of state in this process as an important catalyst (Kim and von Tunzelmann, 1998: 25) and to provide policy implications. Therefore, it draws attention to the complex structure of the system (including politics, culture, markets and technology) and treats the 'indirect' role of the state (via training and mobility of highly skilled people) as a vital ingredient to shape the system. The findings from observations in the Taiwanese IT industry have been useful for shedding light on the role of the state. For instance, Kim and von Tunzelmann (1998: 14-15) state that rather than the *direct* intervention of the state; its *indirect* contribution has been more beneficial for the firms in the industry. Whereas the former is related to establishing the state's own R&D institutes available to firms, the latter involved active training of people and mobilizing them into the firms. With the former, it was found that mostly large Taiwanese firms made use of the R&D institutes, but the latter appealed to SMEs, which formed the majority of firms in Taiwan (pp.14-17). This finding highlights the degree, the means and direction of state intervention in science and technology policy-making. Later, Lee and von Tunzelmann (2005) show that one may expect that there may be different roles of the state in different industries and in different countries. Their results from the science and technology test (a quantitative study) concluded that "subsidies from government are no longer the key 'propeller' which pushes forward the improvement of the IC industry, but foreign S&T transfer is still an essential factor in Taiwan's IC industry. Improvements in process technology, relative to other state-of-the-art technology, in the IC industry in Taiwan more and more deeply depend on the introduction and transfer of foreign advanced technology" (p.440). To sum up, if the innovation system concept is divided into two main components: (i) institutional framework and (ii) knowledge networks, the network alignment approach tries to combine these two components in its analysis of a national innovation system.

One way in which it however differs from the NIS approach is that it envisages the networks that constitute a technological system or a sectoral system as also relevant within and beyond national boundaries. Its important inference is that, unlike in the other systems approaches, there is no expectation that the variously originating networks will 'align' with one another; though again the state may act to point these networks in similar directions, through its 'vision' for the economy and its structure.

2.6 Relating Technological Capabilities and Innovation Systems

Innovation systems approaches place the firm and the other institutions at the core of their concepts narrowly framed with relationships between them (networks) and broadly framed with government policies, culture, education, etc., and the concepts may be bounded by industry, technology or national borders. Except for the SIS approach which has lately located the knowledge base at the centre of the framework and incorporated firm-level learning and technological capability accumulation in the firm into the system analysis (Malerba, 2004), R&D conducted in the firm or elsewhere in the system is the main channel that connects the technological capability concept with the innovation system concept. Therefore, empirical research on innovation systems based on statistical analyses tends to be limited to R&D and patents data. Not only is this kind of data most of the time unavailable or (even if available) unreliable in the developing countries, but also it cannot fully replace the technological capability accumulation concept.

However, recent studies, discussed below, on the knowledge network component of innovation systems search for whether the increasing level of technological capabilities is a reason for emerging and evolving knowledge networks in a system. Before setting these out, I will stress the emphasis on interactive links by scholars in the innovation systems approaches, which provides a strong background for knowledge networks approaches – i.e. knowledge flows among the actors of a system.

2.6.1 Strong Interactive Links in the Innovation Systems Approach

Nelson (1993) mentions the existence of strong national links (maybe industry- and/or product-specific links) to talk about a national innovation system. Porter (1990) and Lundvall (1992) proposed that firms in industries where a country is strong tend to have strong interactive linkages with their upstream suppliers, who also are national firms. Nelson’s (1993) study shows many cases in which this proposition is verified: the Japanese automobile industry, Danish agricultural product processing industry, Italian textile industries are good examples. However, as Nelson again points out, there are a number of examples where this proposition does not seem to hold. Pharmaceutical companies, strong in Germany and the USA, do not seem generally to have any particularly strong supplier connections, either international or national. Rojec and Jaklic (2001), based on surveys made with 26 firms from the car components industry of Slovenia, show that relationships between suppliers and buyers tend to diminish as the type of product moves from high complexity to very high complexity. They cannot give any obvious explanation for this, “except maybe in the case of companies being a part of an MNE, where one would expect higher integration of highly export oriented subsidiaries (what the interviewed companies as a rule are) in a foreign parent company's network" (Rojec and Jaklic, 2001:17). They found, however, that the interactions follow the expected increasing density from low complexity to medium complexity and high complexity products, though they do not give a clear definition of "product complexity", but just rely on the answers from the firms about the level of complexity of their products. These findings point to the fact that increasing technological capabilities in the firm may lead to an increasing number of interactions, but something certainly happens to cause firms to abstain from interacting further when technological capabilities reach such higher levels where firms start to produce complex products or deal with complex processes.

Among the interactive links user-producer interactions especially have drawn attention in many studies within the learning framework (Hakansson, 1987; Andersen and Lundvall, 1988; Johanson and Mattson, 1988; Fagerberg, 1992) and innovation systems (Lundvall, 1992b) and are supported by empirical case studies, though concentrated on developed country firms. Lundvall (1992b) analyses in detail the user-producer (buyer-supplier) interactions within the NSI context and states that user-producer relationships are necessary prerequisites for product innovations, with such interactions being most effective within the national borders because of the existence of cultural and similar effects. However, Lundvall does not identify the content and the direction of the user-producer 'relationship' specifically. He does not differentiate between the firm in question as the user or the producer.[7] From a relationship content point of view, he presumably means trade relationships only when discussing national and international relationships (he gives supporting export relationship examples from Hallen et al. (1987: 60) for a comparison of domestic and international relationships) and elsewhere he means knowledge flows when talking about the quality of information. He does not differentiate clearly between trade relationships and knowledge relationships either. However, knowledge relationships seem to have substantial importance in the innovation systems analysis and deserve to be discussed separately since innovations

[7] User-producer interaction may be handled as either the interaction between the producer (supplier) of the process/product technology to the firm in question which is the user in this case, or the interaction between the user (customer) and the firm in question which is the supplier of the product/process. Thus, the firm in question could be both a user and a producer. Whether this would change anything in the content of its relationships, and would the behaviour of the firm be different in the user role and in the producer role is another task to look at. Lundvall does not think that there will be any difference by not differentiating between the two.

are results of interactions built on knowledge exchange more than trade relations, despite the fact that trade and export relations may also be valuable sources for knowledge acquisition. Lundvall (1992b: 48) also emphasizes product innovations taking place in organized markets where there is interaction between users and producers and where there is communication (meaning a common language), little geographical distance and more importantly less cultural distance between users and producers. He points out that this is one fundamental reason why it is meaningful to define and analyse *national* innovation systems. However, one argument at this point could be that the international interaction of users and producers from similar cultures and development levels could also contribute to the innovation system of a country. In an earlier field study on the copper industry in Turkey, I interviewed engineers in large-scale firms and they stated that they could benefit more from their interactions with the Japanese firms compared to those with the American firms in previous relations, because they felt from the behaviour of Japanese engineers that the Japanese culture and behaviour resembled Turkish behaviour and they felt comfortable with it. Thus, it is worthwhile to study culturally similar nations from the firm interactions and innovation systems point of view.

Von Hippel (1988) talks about *functional* relationships, which may be a potential source of innovation under appropriate conditions. His work may well bring a *condition-specific* nature to the innovation system concept depending on the type of user, who may be quite innovative as in the case of university researchers in the scientific instruments field. Considering more "normal" users like firms in the semiconductor industry, von Hippel (1988) finds that most of the entire innovation process is centred on the user, whereas only commercial diffusion is carried out by the manufacturer. Von Hippel (1988: 29) claims that almost all significant pultrusion process machinery innovations were developed by machine users. This however raises another problem of meanings, because von Hippel defines as "users" firms that others would regard as producers – here the producers of pultruded products. Effectively, for von Hippel, all process innovations other than those developed wholly by "turnkey" suppliers register as user-led innovations.

There are also relations based on knowledge sharing other than user-producer type links in an innovation system. Hagedoorn and Schakenraad (1990) analyse different modes of cooperation of firms, changing from joint venture to licensing agreements, specifically for knowledge exchange, by considering four categories of such buyer-supplier relations internationally without restriction of any borders. They make use of the MERIT-CATI (Co-operative Agreements and Technology Indicators) databank for 4600 cases of cooperative agreements from biotechnology, information technologies and new materials fields. They find the most intense interactions in the information technologies field, followed by biotechnology and finally new materials. The vast majority of the interactions happen to be among the large firms of industrialised countries, namely Western Europe, USA and Japan. The rest of the world accounts for only 5-10% of interactions, according to type of field. When Japan is excluded, biotechnology holds 74%, information technologies 67% and new materials 57% of their knowledge interactions among industrialised countries. When Japan's leading position in new materials is considered, the relatively higher interaction of Japan in this field is self-explanatory. However, figures for Western Europe and the USA are also quite explanatory in evaluating knowledge relations from similarities in culture, language, demand for products in the specified region as a whole and from a factor endowments point of view. Though national policies and therefore the innovation systems differ in each of the Western European countries and the USA, there is still a substantial amount of knowledge interactions going on among the firms regardless of national differences. However it is striking that the density of interactions reaches its peak in the rich regions of the world where culture, language, demand and factor conditions are closest to each other. As Nelson (1993) also points out when discussing the difficulties with the NSI, borders around nations are porous and increasingly so, and it is safe to say that there will be increasing internationalisation of technology.

Consequently, authors emphasizing strong interactive links in the innovation systems concept implicitly were aware that strong, productive, competitive industries and firms (in other words firms with strong technological capabilities) tended to interact more with the outside world. The question then was how technological capabilities influenced networking.

2.6.2 An Analytical Approach: Knowledge Networks in the Innovation System Concept

Some authors tend to differentiate knowledge networks from others – e.g. production networks or trade networks – in an attempt to understand more about change-generating technological activities in the firms that evolve over time. Among them, Hakansson (1987, 1989), Gelsing (1992), Bell and Albu (1999), Giuliani and Bell (2005) and Dantas (2006) focus on knowledge networks, their characteristics and the role of actors and interactions in knowledge networks. Such separation also allows for in-depth understanding of knowledge flows between firms and their partners that form the background of the innovation system concept.

In his early studies, Hakansson (1987, 1989) highlights the importance of industrial networks especially between the suppliers, customers and producers in the industry. Even though his approach mostly excluded the non-firm organisations and the role of internal technological activities in the firms, it was useful in initially attracting attention to inter-firm relationships in product innovations and provided valuable examples of how different types of actors interacted with each other – i.e. vertical and horizontal cooperation between firms. He (1987: 8-17) identifies actors, relationships and resources as the characteristics of networks; resources being "physical assets (machinery, materials, etc.) financial assets, and human assets (labour, knowledge and relationships)" (p.16). Hobday (1994: 240), on the other hand, warns that a wide variety of industrial networks attracted a lot of attention during the 1980s, but the concept lacked a clear definition in the literature.

As the literature moved towards differentiating knowledge networks from other kinds of networks, the former were better clarified. For instance, Gelsing (1992:117) clearly distinguishes between trade networks and knowledge networks: The former focus "mainly on linkages between users and producers of traded goods and services" and the latter focus "on the flow of information and exchange of knowledge irrespective of its connection to the flow of goods". In line with Hakansson (1987), Gelsing (1992: 118) also identifies any network being composed of "nodes and relationships" and the nodes being "the industrial firms and their innovative partners, be it suppliers, customers, private and public consultancies and competitors".

Then, in the 1990s, along with the understanding that "technological change is not simply something firms choose and buy-in from outside, but it is rooted in a specific set of change-generating resources or capabilities which are located *within* the structure of technology-using firms" (Bell and Albu, 1999: 1718), the firm-driven nature of knowledge networks came under investigation in the literature. By then, many authors have stressed that successful knowledge networks were a combination of external knowledge flows into firms as well as internal activities in the firms and their knowledge absorption levels (Cohen and Levinthal, 1990; Bell, 1997; Kim, 1997; Howells, 2000).

Among these studies, Kim (1997: 91-4) touches upon the institutional environment framework as another important source of technological learning. It comprises the international community, the domestic community, as well as the in-house efforts of the firm, which help develop technological capabilities as a by-product of operations through learning by doing.

Bell and Albu (1999) examine knowledge networks within what they call knowledge systems (particularly in industrial clusters) and state that a knowledge system encompasses major differences from a production system. While the former are identified with "stocks and flows of knowledge" (p.1722) between firms and their partners which underlie change-generating technological activities in the firms, the latter remains confined to routine activities related to the production of goods. In fact, they explicitly state "knowledge flows can occur into the firms from outside the system, between firms and other institutions within the system or indeed internally within firms themselves" (p.1723). In their study of a Chilean wine cluster, Giuliani and Bell (2005: 64) observed, "…the channels of knowledge acquisition and diffusion *between* the firms were key components of the overall cluster absorptive capacity. However, the density and structure of the channels of knowledge acquisition and diffusion *between* the firms into and within the cluster, and hence their impact on the extent of learning in the cluster, were strongly shaped by the knowledge bases of the individual firms." Giuliani and Bell (2005) challenged the views in the literature that clusters provide good habitats for technological learning for firms irrespective of their level of knowledge base since the expectations were that the knowledge diffusion within the cluster allowed all cluster firms to get hold of knowledge available. On the contrary, they (2005: 65) state that

"…measures designed to foster intra-cluster communication and collaboration might not do much to change firms' cognitive roles if those are shaped primarily by their knowledge bases". Similarly, in her extensive case study of Brazilian offshore oil company PETROBRAS (Petrolero Brasileiro SA), Dantas (2006: 237) concluded that "shifts in the properties of knowledge networks were preceded by shifts in the company's capabilities and changes in the capabilities of the company were a pre-condition that enabled it to develop its knowledge networks into qualitative new forms."

As a consequence, the knowledge network approach provides a useful tool by focussing on knowledge flows and allows for feasible empirical analyses with certain measurable parameters as compared to "the classical measure R&D expenditure as percent of GDP" that Lundvall (1992a) used in national innovation systems studies. This research makes use of the knowledge network approach as an empirical tool, but does not undermine the cumulative role of studies conducted within the innovation systems approach that clarified the vital ingredients of a system in its narrow definition, that is 'actors' and 'interactions'. However, very little of the innovation system literature observes that 'the system is changing over time'. Having said a lot about the networks, actors and the institutional structure, it does not inform about how these elements change over time particularly in a late-industrialised world. Therefore, further research is needed to trace and highlight the changes over time in the characteristics of the innovation system.

2.7 Conclusion

This chapter has presented the literature on firm-level technological capabilities, technology transfer and innovation systems. It has also discussed previous studies about linking technological capabilities and technology transfer concepts, and technological capabilities and innovation systems concepts.

Literature on technology transfer provides good insight into the mechanisms that occur in receiving technologies from both foreign and domestic sources. There is a wide range of tools to select from when acquiring technology in the developing country firms. Yet, the base of knowledge in the recipient firm always plays a substantial role in gains achieved from the transfer. It is widely accepted that firms with sufficient levels of knowledge base and commitments to seek knowledge make better use of the technology transfer process, increasing their level of capabilities even further.

Different approaches to the innovation systems concept in the literature highlight the networks, their actors and the institutional framework as the main elements of a system. They mainly deal with the existence of system elements, emphasizing the firm and the research institutions as its main actors. They also deal with other factors such as government policies, or cultural and linguistic circumstances, although seen as secondary elements supporting a system. Despite the fact that secondary elements are decisively highlighted in innovation systems approaches because they are seemingly important, it is very difficult to study their effects empirically. Knowledge networks being essentially at the heart of an innovation system whether it is national, sectoral, regional or global seem to be appropriate and useful tools to study innovation system concept empirically. However, the innovation system literature tells us almost nothing about the changes occurring over time regarding the system characteristics and the reasons why this happens.

Consequently, there is need for further research. Therefore, as well as linking firm-level technological capabilities with the elements of the innovation system concept, this research will trace changes over time in an emerging innovation system in a late-industrialised country. The section to follow proposes a framework for the analysis of technology transfer, technological capabilities and innovation system concepts. The details of the framework and the methodological approach to the analysis are presented in the next Chapter 3.

2.8 Analytical Framework for this Research

The analytical framework for this study is formed as demonstrated in Figure 2.2 below for a firm-level analysis by which the technology transfer process (TT_1, TT_2… TT_n representing different modes of technology transfer) and the variables (V_1, V_2 and V_3) affecting the accumulation of firm-level technological capabilities act as ways of integrating knowledge for the firm and influence both the outcomes (as brought into the analysis in the form of technological capability assimilation) and the innovation system. In the framework, V_1 denotes the existing knowledge base of the firm, which encompasses the knowledge about the technology already being used in the firm, the ability to solve existing problems with the technology used, and the characteristics of skilled labour in the firm (number of engineers in different departments of production chain, etc.). V_2 denotes the intensity of effort by the firm, which shows the existence and intensity of R&D and design facilities, organisational structure of the firm, mobility of skilled labour within other firms and institutes, personnel training facilities, involvement in technological projects, etc. And V_3 denotes the capabilities gained from system interactions of the firm such as those with other firms and research units.

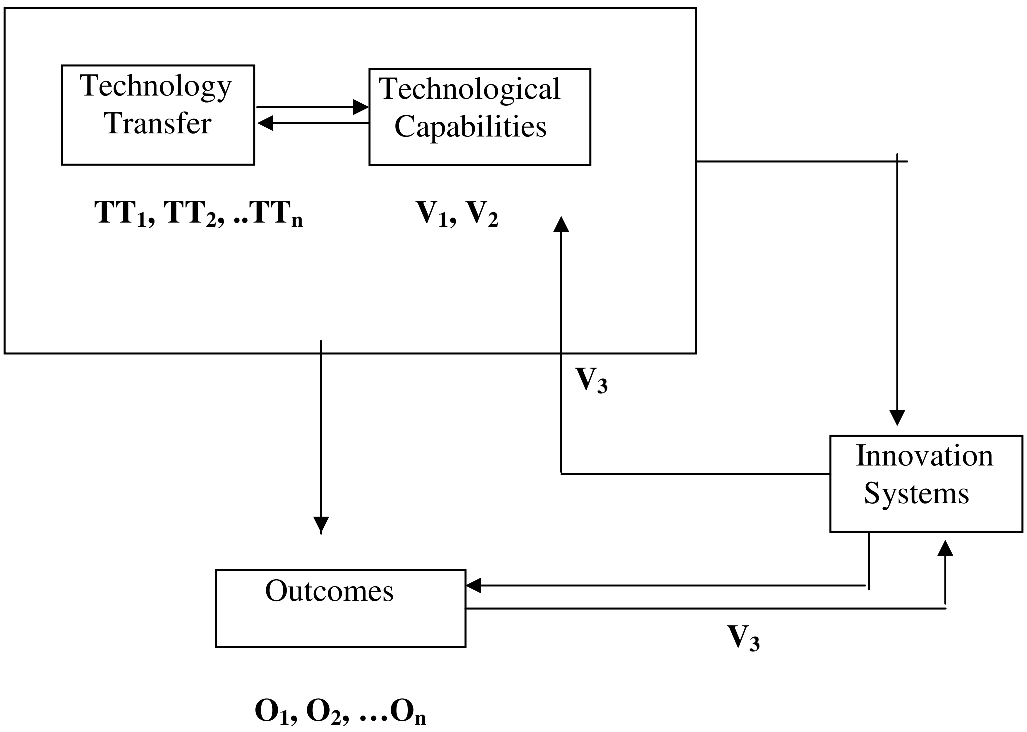


Figure 2.2 The relations between technology transfer, accumulation of technological capabilities and innovation systems

In other words, the strength of knowledge integration in the firm determines the activity degree of the innovation system and this degree is confirmed by the achieved outcome. The innovation system affects outcomes through the interaction systems of the firm and other variables external to the firm such as the policy structure in the country, cultural effects, etc. Most of these variables, indeed, are explained by the interactions between the elements of an innovation system, and just at this point the methodological claim of this research holds that Innovation Systems studies regarding an industry should be conducted through in-depth case studies of firms, which is also stated in Archibugi et al. (1999) as, “There is still much to be learned regarding how firms respond to, and interact with, the innovation system (national, sectoral or otherwise) at any point in time.” The firm’s own inner capacity to activate capabilities and its linkages with the outside world are ways to approach the Systems of Innovation concept in a more focused manner.

Outcomes (O_1, O_2 …O_n) are the final results about the level of technological capability assimilation that the firm has achieved after transferring the technology it needed. Those outcomes differ according to the type of transfer taking place, as well as according to the types of linkages of the firm built in the aftermath of the transfer process. Moreover, not all of the expected outcomes might have influence on the innovation systems.

This study tries to capture the level of factors that are influential on the emergence of innovation systems from a firm-centred approach and analytical design. The aim is to be able to keep the analysis as simple as possible, because the introduction of each influential factor as separate from the firm- and industry-specific facts has the tendency to introduce further errors and complications.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter first discusses the research questions, which are based in the theories of technology transfer, firm-level technological capabilities and innovation systems, as discussed in Chapter 2. It elaborates the research methodology, i.e. the theoretical background of the research design, the way the research is designed and the concepts operationalised, criteria for selection of the industry and the sample, data acquisition by semi-structured face-to-face interviews, qualitative data processing into quantitative data, the unit of analysis, and the data methods of analyses that are used to examine the research questions.

3.2 Interrelating the Research Questions and the Key Concepts

This study mainly aims to provide a framework for the emergence of *innovation systems* in the developing country context, by first analysing the contribution of the *technology transfer* process in the firm to the improvement of its *technological capabilities*, and secondly by analysing the influence of improved capabilities on the emergence of an *innovation system*. Since the acquired skills and knowledge in workers, facilities and organisational systems might be transformed into both production and technical change activities through interactions between elements of the system, technological capabilities act as a bridge from the technology transfer process towards innovation systems. Innovative capacity itself has a strong relation with technological capabilities acquired through learning by means of technology acquisition activities.

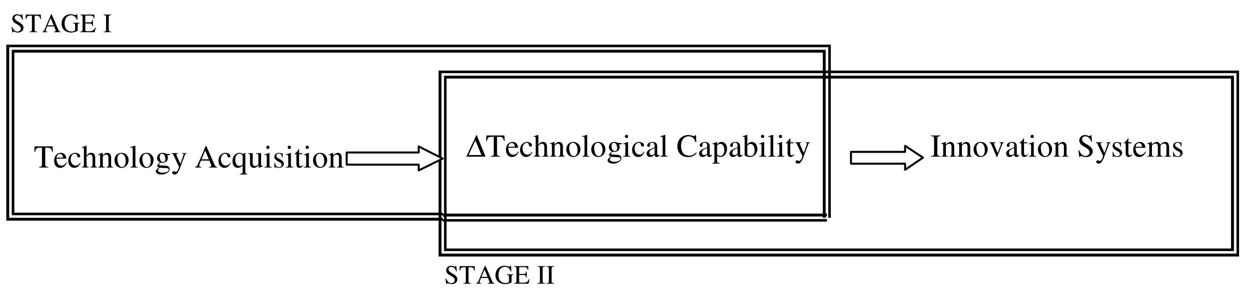
Thus, utilising the abovementioned three concepts, the ultimate aim of this thesis is to answer the following main research question:

- **How do innovation systems emerge and change in a developing country context, and how are they influenced by the technology transfer activities?**

A two-stage research is designed (see Fig. 3.1) to work on the major objectives of the study and to answer the sub-questions below, which elaborate the main research question:

- How does the transfer of technology influence technological capabilities at the firm level in the materials industry in Turkey?
- How do the increments in technological capabilities from the technology transfer process influence the emergence and the elements of the system of innovation in the materials industry in Turkey?

Figure 3.1 Three key concepts used in this two-stage research



The overall analysis does not encompass the whole set of relationships outlined earlier and summarised in Figure 2.2 in Chapter 2. In particular, although that figure and the associated discussion suggests a circular relationship running from (i) technology acquisition by firms, to (ii) their paths of capability accumulation, to (iii) features of the innovation system, and back again to (iv) features of technology transfer by firms, the analysis does not examine that whole loop. Instead it focuses only on the two relationships between the first three sets of phenomena (see Fig.3.1):

(a) between key features of the way firms acquire technology and their paths of capability accumulation;

(b) between their capability accumulation paths and changes in key features of the innovation system.

3.2.1 Relating Technology Transfer to Technological Capability Accumulation in the Firm

This section aims to establish what characteristics of technology transfer are related to the increments in technological capability of the firms. As first elaborated by Cohen and

Levinthal (1990), the exploitation of externally acquired technology requires the creation within the firm of some ‘absorptive capacity’. Moreover, the choice, or mode, of technology transfer is a function of the attributes of the technology, as well as attributes of the technology receiving firm or industry (Contractor, 1998:321). Thus, it follows that the absorptive capacity of the firm from the technology it has acquired and the mode of technology transfer itself can be investigated as characteristics of technology transfer that can be related to incremental increases in the technological capabilities of the firms (Fig. 3.2).

Figure 3.2 Analysis of technology transfer and technological capabilities: Key concepts and variables

Technology Transfer Process

*Existing knowledge base of the firm
*Intensity of effort by the firm
*Mode of technology transfer

ΔTechnological Capability

* Increment in capability

3.2.2 Relating Technological Capabilities to Systems of Innovation

In this analysis, the effects of elements of technology transfer (as reflected in the incremental technological capabilities) on the determinants of an innovation system are studied (Fig. 3.3). In the existing concepts of innovation systems in the literature, learning (Lundvall, 1992), cumulativeness of technological knowledge and nature of knowledge base (Breschi and Malerba, 1997), and economic knowledge and competence (Carlsson and Stankiewicz, 1995) are placed at the heart of the system. Learning plays a major role in the development of the system, whilst forming the key element in its connectivity (Archibugi et al., 1999:530). Thus, the origin of linkages – i.e. domestic or foreign, source of knowledge and the frequency of linkages in the system, can be investigated as the characteristics of an innovation system that relate to the incremental increases in technological capabilities of the firms (Fig. 3.3).

Figure 3.3 Analysis of technological capabilities and innovation systems: Key concepts and variables

ΔTechnological Capability ⟹ Innovation Systems

*Increment in capability

*Origin of link in the system
*Type of source in the system
*Density of links

The various approaches to the innovation systems concept defined in the literature, particularly the National Systems of Innovation (NSI), Technological Systems (TS) and Sectoral Innovation Systems (SIS) are discussed in detail in Chapter 2 above. Each of them has its very tidy order in itself, but the definitions of the system as a whole and the constituents of the systems differ profoundly, and thus the concept becomes confusing. On the other hand, as Edquist (1997) mentions, different approaches of innovation systems may be fruitful – but for differing purposes or objects of study. This research does not restrict itself to any of the innovation systems definitions, but by utilising the studies previously developed, tries to explain how innovation systems emerge and change regarding a developing country.

3.3 Restrictions on the Concepts of the Research

Various agents are credited with a role in developing and changing systems of innovation, including the state, bridging institutions, etc. The variables of the analyses in this thesis are chosen only as those related to the firm and the industry. On the other hand, factors such as government policies, historical experience, national education and training system, cultural effects, etc., are kept outside the study in the first instance. They may cause the research to be so broadly framed and prevent it from reaching reliable results and making generalisations.

Even though relevant data are collected, interactions with finance suppliers and interactions with bridging institutions are not included in this study. Bringing in more variables would complicate the study further. Moreover, the data show that the role of bridging institutions and finance institutions is currently at a minimum level. In the great majority of cases, it is the effort of the firm’s manager in forming links.
To sum up, in this thesis, the firm, being at the core of all systems of innovation concepts, will be the relevant area chosen to investigate the emergence of innovation

systems. Being a dynamic production unit endowed with certain level of technological capabilities and having linkages, which are both the causes and results of these capabilities, the firm remains the crucial element of all relevant treatments of the systems of innovation concept. However its role has been less commonly analysed when compared to some of the other agents. This study will try to fill this gap.

3.4 Research Design

3.4.1 Rationale for Choosing the Materials Industry

The materials sector involves manufacturing of metals, ceramics, composites and polymers.[8] Starting mostly from the 1970s, there has been an increase in the awareness and studies of advanced materials especially in the industry and universities in the developed parts of the world[9] and these materials started replacing the traditional materials such as wood, iron, standard steel, copper, aluminium, etc. in most applications. Today, the materials sector has evolved into a science-based, knowledge intensive and higher value-added high technology sector, which delivers products for almost all other industries, from automotive to cutting tools, machinery, casting, textiles, furniture, aerospace, telecommunications, energy, electric-electronics, chemicals, defence and biomedical. Thus, the materials sector distinguishes itself as a sector, which can connect its own dynamism to other related manufacturing sectors. This arises mainly due to the increasing cost-effectiveness and high-performance of advanced materials in comparison to traditional materials.

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[8] Appendix A presents in detail the types of materials and their production methods. Also, Section 4.3 in Chapter 4 presents some insight about the types of materials produced in Turkey.

[9] Indeed, the "Materials Science field emerged in the USA some time in the early 1950s and for a number of years developed only in that country. Its development elsewhere was delayed by at least a decade. Northwestern University, in Illinois was the first university to adopt materials science as part of a department title that grew out of a department of metallurgy. Head of department was a metallurgist who has been doing research at Bell Laboratories." (Cahn, 2001: 3). Along with the activities in the universities "a few industrial research and development laboratories were already applying ideas of materials science and engineering (MSE) even before those ideas had acquired a name. At Bell Laboratories, semiconductors, germanium and silicon were processed, which were required for the manufacture of transistors and diodes. Nylon was brought into the market as a result of research conducted at Du Pont Research Station. The General Electric Laboratory made major contributions for introduction and perfecting the techniques of manufacturing ductile tungsten for light bulbs" (Cahn, 2001: 8). In Turkey, however, "the first research work on advanced ceramics started in the Middle East Technical University (METU) in Ankara after 1974 when new faculty members joined the School of Engineering from the USA. Activities on slip casting of pure oxide systems were initiated and new courses were offered at an advanced level on the basic science of ceramic processing." (Toy and Baykara, 1994: 202). And, it was not until 1995 when METU metallurgical engineering department acquired "Materials Science and Engineering" name.

The developing countries, however, until recently remained as the exporters of raw materials for the manufacturing of advanced materials only to be re-imported as finished products (Sikka, 1995). Also, with the declining world demand for basic metals such as iron ore, aluminium, copper, etc. and the "low consumption growth of metals as now considered to be a characteristic of mature developed countries" (Lastres, 1997: 78), many developing countries' export structures were adversely effected. Therefore, they had to develop strategies to overcome the problems, confront this major technological revolution and catch-up with the developed countries.[10] The catching-up process is closely associated with making use of windows of opportunity and early entry into *new* technology *systems*, so leapfrogging to fast growth in a developing country (Perez and Soete, 1988: 477-8). The materials industry fully encompasses the dynamic and vibrant characteristics to examine such process in a developing country. Moreover, it inherently allows for a comparison of emerging science-based technology and the mature relatively lower-technology parts of the materials industry in Turkey (see Section 3.4.4 for more explanation).

Finally, another reason for choosing this specific field of materials comes from the author of this thesis having a metallurgical engineering background as a BSc degree and the prospective thought that this would make an enormous contribution to this research in the way that it would ease making it possible to understand the process and product technologies better and in detail, and help to place the necessary comments in terms of capability achievement.

3.4.2 The Sample

As explained also in Chapter 4, in total there were around 75 firms in the materials field of the manufacturing industry of Turkey by the end of 2000 (Baykara, 1998: 107-26).

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[10] For instance, in 1986 Ministry of Science and Technology in Brazil created a National Commission on New Materials, which were in charge of financing R&D activities in the universities and firms (Lastres, 1997: 83). Similarly, India set up several national bodies to run research programmes on development of selected new materials by joining forces with selected distinguished universities of the country one of which was a National Superconductivity Program started in 1988 and was completed in 1991 (Sikka, 1995). Turkey announced in 'Turkish Science and Technology Policy Document: 1993-2003' that gaining technological capabilities especially in the fields of critical technologies of ICT, *advanced materials* and biotechnology was aimed and set targets for increasing R&D expenditures, number of researchers, etc. as well as creating bodies responsible for implementation of these aims (see Section 4.4 of Chapter 4 for detailed policy measures taken in Turkey to create an innovation system embracing high technology sectors.) However, identifying the policy measures is not sufficient for the realisation of technological advances in the industry.

A pilot survey is used as a tool for selection of the firms from the Turkish materials industry to form the sample. For this reason, in September 2000, a one-page exploratory questionnaire and a cover letter were faxed to 26 firms from the materials industry.[11] These 26 firms were identified after consultations with TTGV[12] (Turkish Technology Development Foundation) experts and other key experts in the field who have chairs at government research institutes and universities. In-depth Internet search was also conducted.

The pilot survey aimed to get preliminary information about firm size, product types, new products introduced into the market, export activity, existence of R&D, number of engineers and researchers, interactions with other actors to get new technologies and acquisition of main production technology of the firm. It was expected that firms in the materials industry would be producing high-complexity products with high-tech production technologies. However, results from the pilot survey highlighted the emergence of a complication that, as shown in Chapter 4, the materials industry in Turkey could be grouped into two segments, as mature and science-based segments. Because it seemed likely that ignoring that difference would create substantial problems at the later data analysis stage, two options were considered, to 'design out' the difference and focus on only one of the two segments, or to include both as the basis for potentially interesting comparison (see section 3.4.3 and 3.4.4). Although the need to split and the overall industry sample added complications to the design of the research, the second option was chosen.

11 firms were distinguished from the rest by the use of higher technology production processes and products. The previous research done on materials and their production technologies proved to be very helpful in distinguishing the firms belonging to the science-based segment of the industry, such as identifying the use of the physical vapour deposition technique for production of ultra thin film ceramic coatings on metal or glass surfaces.[13] At this point, to confirm the reliable selection of science-based technology firms in the sample, further information was sought from TTGV. TTGV

[11] Individuals in administrative or managerial positions were contacted. All of the firms answered the exploratory questionnaire, though some of them only after persistent reminding by telephone.
[12] TTGV is a World Bank sponsored NGO in Turkey (see Chapter 4).
[13] Definitions of the 'materials' concept are given in Appendix A.

financially sponsors R&D projects of Turkish SMEs. Hence, 11 out of the 26 firms had R&D projects sponsored by TTGV at the time of selection. These projects consisted either of development of a new product for the domestic market or development of a novel production process in the firm. However, one of the 11 science-based technology firms declined the interviews at the next stage, leaving the sample with 10 science-based firms. As highlighted further in Table 3.3 most of these firms also are distinguished from the others, with percentages of researchers and engineers above 20% in the total workforce.

The remaining 15 mature technology firms included those using relatively medium technology processes and interested in extending their product range using new process technologies, and also those engaged in totally low-tech process and product technologies. Among the first group, there were a few firms that undertook agreements with TTGV on financial sponsorship of an R&D project as well. These firms are engaged in lower technology products with use of medium technology production technologies, such as a hydraulic press for production of metal powder composite parts produced especially for the automotive industry. Some of these mature technology firms actually started their life with quite mature activities, but at a time in their life they started with science-based projects along with their mature activities. Despite that, these firms are regarded as mature technology firms in the sample, because science-based projects do not prove to be their sole activity as for the other science-based technology firms in the sample. Out of 15 mature technology firms, five firms declined to be interviewed at the next stage and one firm closed down before the interview was conducted. Thus, nine firms formed the sample for mature activity firms. Table 3.1 summarizes the figures for creation of the sample.

Table 3.1 Number of firms in the population and the sample in 2001

	Science-based technology firms	Mature technology firms	Total
Population	27	48	75
Initial Selection	11	15	26
Final Sample	10	9	19

3.4.3 Sample Reliability

Since the database used in this research is compiled through face-to-face interviews and it extends through a time period of 35 years, there is some concern about the reliability of the sample and the database derived from it. The sample consists of 19 firms. As stated previously, it is thought that there are about 75 firms in the materials industry in Turkey. Therefore, the sample represents 25% of the population as of 2001. In this sample the population of science-based technology firms are represented by 37% and mature technology firms are represented by 19%.

Regarding the knowledge links, information about 19 firms in the sample is available. There is no information about the interactions of rest of the firms in the materials industry. There have been no available data gathered about such interactions previously. There were on average 1.4 actively used links per project (19 firms were involved in 289 projects from 1967 to 2001); this provided a total of 408 observations over the 35-year period (which formed the primary database). 191 observations belong to the mature segment of the industry and 217 observations belong to the science-based segment of the industry.

Table 3.2 Allocation of knowledge links by years

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
year	**count**	**%**	**count**	**%**	**count**	**%**
1967-71	7	1.72	3	1.38	4	2.09
1972-76	13	3.19	4	1.84	9	4.71
1977-81	7	1.72	4	1.84	3	1.57
1982-86	14	3.43	2	0.92	12	6.28
1987-91	34	8.33	17	7.83	17	8.90
1992-96	93	22.79	58	26.73	35	18.32
1997-2001	240	58.82	129	59.45	111	58.12

[a] N=408, [b] N=217, [c] N=191.
Source: Author's own data.

As shown in Table 3.2 almost 60% of the links (whether for the total sample or science-based technology firms or mature technology firms) arose within the last five years (1997 to 2001) and 75% of the links occurred within the last ten years (1992-2001) of the period under examination. It may have really happened that firms had fewer projects and therefore links during the 1970s and 80s, or this may be so because of a recall problem: the further back the data requested go, the fewer the number of projects and therefore the number of links remembered by the interviewees. There are grounds to believe that recall over 5-10 years is reliable and therefore changes in the last 5-10 years are moderately valid. However, there are also grounds to believe that during the 1970s and 80s knowledge-seeking interactions of firms were much less common (e.g. collaborative agreement modes of technology transfer links amount to only 9 from 1967 to 1986 and arm's length modes of technology transfer links to 24, while from 1987 to 2001, the former come to 171, whereas the latter are just 102 links).

Indeed, the 19 firms examined in this analysis are domestic family-run small and medium sized enterprises by ownership structure. The vast majority of the managers in the sample firms have been managing the firm since its establishment. In a few older firms, the son or daughter of the owner took over the managerial position, but in such cases it was possible to meet and interview the first generation manager as well. Additionally, frequent opportunities to meet chief engineers of production and especially R&D units, who in some cases worked in the firm since its establishment was always taken.

Therefore, significantly fewer links during the early years of the examined period cannot only be due to a recall problem. It can also be explained by significantly smaller number of interactions in that period. Therefore, I need to rely on the firm sample representation and the sample is moderately representative of the population.

3.4.4 Means of Comparison and Commonalities

The main framework of comparison for this research is provided by the contrasting and emerging science-based technology and the mature relatively lower-technology parts of the materials industry in Turkey. Based on the structural and technical differences between these two segments of the industry, a two-fold division of materials industry in Turkey is introduced in this study:

1. Science-based technology firms that are producing high-complexity novel products with technology implementations related to these products and their processes.

2. Traditional firms that are producing relatively conventional and mature products with technology implementations related to these products and their processes.[14]

Therefore, different maturity of technologies, different sources and accessibility of the technologies, different product life cycles, and expectations of different results relating to innovation systems with regard to each one are set to be the basis of comparison. On the other hand, to put the comparison on an acceptable basis and to be able to interpret the collected data, commonalities between them are concerned only with private and small and medium scale firms from the materials industry. Two firms had employee numbers of 385 and 497, being larger than other firms in the sample; however all firms have under 500 employees as fits the definition of an SME from the employment point of view. On the basis described above, the comparison here resembles very much Kim et al.'s (1989: 34-37) small firms with high capability (science-based technology firms) and small firms with low capability (mature technology firms), which in turn are expected to exhibit dissimilar patterns of technological capability accumulation and linkage characteristics.

Table 3.3 gives an illustration of the types and employment figures of the firms in the sample. Mature technology firms are identified with a larger number of employees and lower percentages of researchers and engineers in their total workforce. On the contrary, science-based technology firms exhibit much higher percentages of researchers and engineers, with a smaller number of employees.

[14] Section 4.3 in Chapter 4 provides further information and the basis for comparison of the science-based and mature segments of the materials industry by explaining the types of products that both segments produce. Appendix A provides in-depth information on the materials industry, some major types of production processes used and the products produced.

Table 3.3 Types and employment figures of the firms in the sample

		At Establishment			During final technology project in 2001		
		A	B	C	D	E	E/D
	Firm	Establishment year of the firm	Number of employees	Number of engineers & researchers	Number of employees	Number of engineers & researchers	Engineers & researchers as % total employees
Science-based technology firms	1	1969	11	1	50	3	6
	2	1979	11	1	32	10	31.3
	3*	1984 (1994)	1000 (100)	120 (10)	1941 (100)	428 (20)	20
	4	1989	6	1	4	1	25
	5	1991	<50	<3	385	69	17.9
	6	1993	2	2	20	2	10
	7	1994	1	1	8	3	37.5
	8	1996	2	1	2	1	50
	9	1996	2	2	6	4	66.7
	10	1998	2	2	8	5	62.5
Mature technology firms	11	1967	11	1	86	11	12.8
	12	1971	5	1	100	6	6
	13	1971	150	12	497	38	7.6
	14	1973	10	2	180	8	4.4
	15	1976	50	1	22	2	9.1
	16	1989	20	1	101	6	5.9
	17	1989	25	4	15	2	13.3
	18	1990	8	1	12	2	16.7
	19	1993	17	0	33	3	9.1

* Firm 3 was founded in 1984, however activities particularly in medium and high technology materials field started in 1994. The numbers of employees and engineers associated with those types of activities are given in parentheses. Technology projects launched before 1994 are not excluded from this research, since technological capability accumulated in these projects paved the way for introduction of activities in the advanced materials field.

3.4.5 Method of Data Acquisition: Face-to-Face Interviews with the Firms

As explained in Chapter 2, this thesis focuses on the relationship between three phenomena in Turkey:

(i) the ways in which firms in the materials industry acquired their technology;

(ii) the paths of technological capability accumulation followed by those firms;

(iii) the changes over time in key features of the innovation systems within which these firms were embedded.

No existing data sources provided information about these issues in this industry in Turkey. Among other sources of data, the archives of firms could be used provided that they existed; however none actually existed.

The broad strategy in this study was therefore to conduct an original survey among firms in the industry. Further, because the common experience of postal surveys in this area involves very low response rates, and also because qualitatively ‘rich’ and detailed data were required to illuminate the key issues taking place over considerable periods of time in each firm, it was decided that the survey should be based on interviews with key informants in the firms. Moreover, because experiments with undertaking these interviews by telephone proved unsatisfactory, it became necessary to conduct face-to-face interviews during visits to the firms. At the same time, an important aim was to undertake a study that would permit significant quantitative analysis, and not merely a small number of case studies, to eliminate subjectivity as much as possible.

Therefore, the data for this research were collected through face-to-face semi-structured interviews[15] with individuals from 19 firms during May-June 2001. This questionnaire format was appropriate to be used as a general guide to provide standardization for the data to be collected. It also had the advantage of allowing for focused questioning in a formal way and providing some flexibility to adapt to the wide variety of circumstances in the firms. In this way, it was possible to prevent the strained atmosphere that could be created by strictly designed questions with pre-determined multiple-choice answers, which could lead to the loss of important issues. Interviewees responded very well to a relaxed, conversational interview format. They were willing to share their information. For instance, the interviewees revealed stories about a number of technology acquisition implementations in the lifetime of a firm. The minimum time for an interview happened to be 4 hours with each individual interviewee. The interviews were always complemented by a visit to production sites accompanied by an engineer of the firm. These moments happened to be an invaluable opportunity to confirm some of the information given by the main interviewee or at least to double-check some important information gathered.

In addition to interviewing representatives from companies, interviews were completed with representatives of key knowledge production institutions in the materials field, such as metallurgical engineering and materials science departments of universities, materials departments of national research centres, and officials of ministries with responsibility for science and technology, such as directors of the technology development centres where some firms in the sample are located. These interviews and thus personal contacts were especially helpful in building relationships based on trust

[15] The interview questions are provided in Appendix B.

with the managers of the companies in the sample. My knowing the professor at one institute, with whom the firm probably is engaged in a project, readily paved the way for a trust relationship with the company. Moreover, in cases of research projects conducted with universities or research institutes, these auxiliary interviews were sources of valuable information regarding the details of specific projects and the actual role of the firm in those projects.

The questions in the main questionnaire were developed in accordance with the analytical framework discussed previously in Chapter 2. The questionnaire covered the following information:

1. and 2. General historical background information about the firm, where questions related to the past and present of the firm were raised. These questions aimed to pick on the year the firm started its activities, the number of employees at the start and at present, size, range of products previously and at present, amount of sales at the start and at present, type of customers at the start and at present, rate of growth since the beginning, and identification of change of technology projects.

3. Link-specific information on technology acquisition and capabilities in the firm draws on measures of technological capability accumulation, details about the main process technology currently in use and other and secondary process technologies that have been transferred previously, and

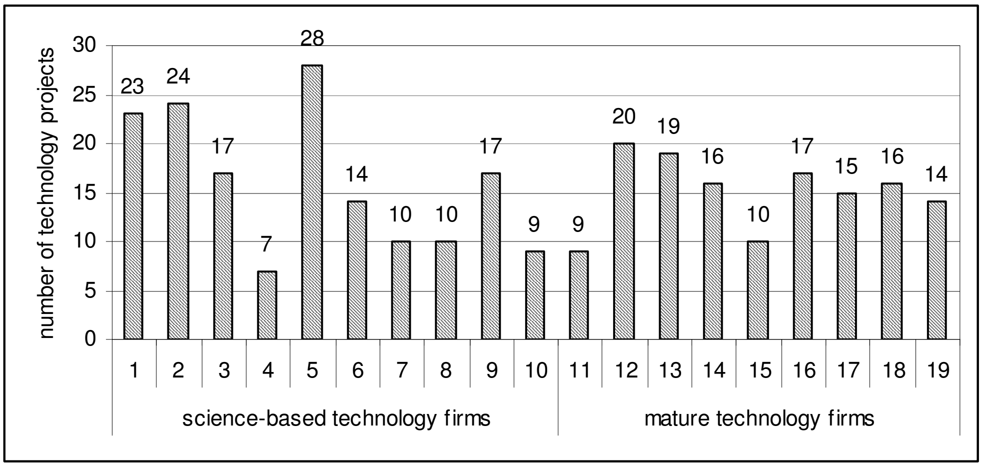
4. Firm interactions elaborate knowledge links from the domestic and foreign communities.

3.4.6 The 'Technology Project': An Intermediate Tool

The 'technology project' concept is introduced as an intermediary tool in this research. It is defined as any type of firm activity that the firm undertakes for acquiring technology, as well as the specific production and research activities with knowledge flows. Each technology project actually resembles a knowledge creating activity, each addressing a solution to a particular problem in the firm, as widely discussed in Nonaka et al. (2000).

Therefore, within each firm, information about technology transfer was sought with respect to each of a sequence of 'technology projects' through the life of the firm. This provided a basis for examining whether and how this aspect of firm behaviour changed over time and differed between firms and industry segments. Since there were on average 15 projects per firm, this provided a total of 289 observations for many parts of the analysis. The number of technology projects of firms is shown in Graph 3.1.

Graph 3.1 Distribution of technology projects by type of firm



Note: Firms are numbered according to the earliest year of establishment.
Source: Author’s own data.

As observed in the firms, the first technology project in each firm is identical in content and is always related to the establishment of the firm. The rest of the technology projects in each firm possess different kinds of content. These are activities ranging from arm’s length activities such as simple transfer of machinery, transfer of production process together with a licence agreement, know-how transfer to collaborative activities such as inter-firm marketing activities, joint ventures, external problem-solving activity, customer oriented development, technical assistance and cooperation, inter-firm strategic technology alliance, firm-research institute technology partnering, subcontracting and brain gain. This analysis spreads over the 35 years from 1967 to 2001, with the earliest establishment of a firm in 1967. There were years in which there was no technology project conducted. There were six technology projects in years 2002 and 2003 of which four were ‘intended’ projects that have actually not been realised and two that were already agreed upon to start at the time the interviews were conducted. These six projects are excluded from the data during the overall analysis, for the reason that they can distort the results obtained, since the final results from these projects were unknown at the time of the interviews.

Firms with more technology projects could be called ‘actively knowledge seeking’ firms, since each technology project identified actually involves acquisition of some kind of knowledge. Moreover, launching a technology project is indeed an indicator of the effort of the firm towards sought knowledge. Therefore, a relatively young science-based activity firm may have more technology projects than a mature activity firm, such as firms 1, 2 and 5 in Graph 3.1. Also, it does not necessarily mean that a mature technology firm always conducts mature and relatively low-technology content projects. It is likely that some mature technology firms can even get involved in high-tech projects as time goes on and the firm builds up sufficient technological capability by learning from its previous projects.

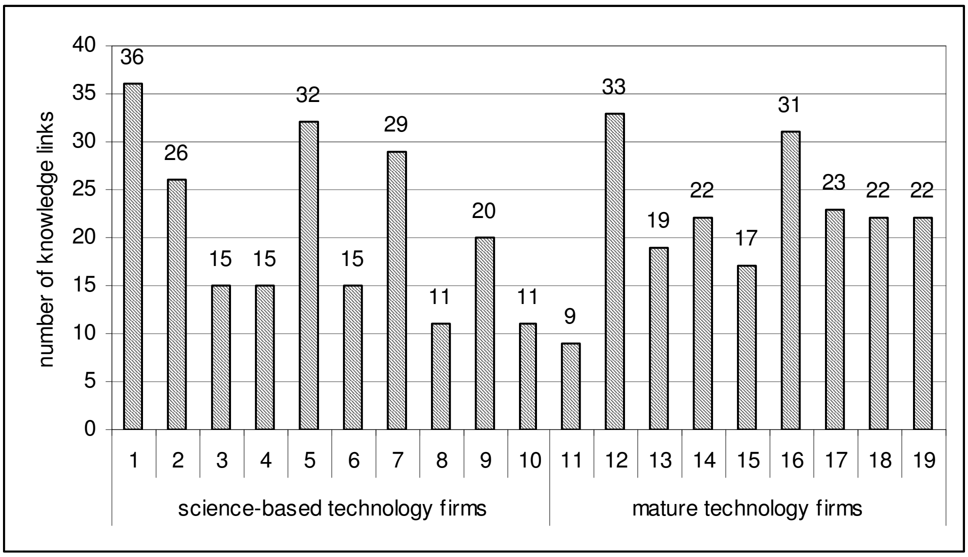
Lastly, one issue related to the ‘technology project’ needs to be clarified. The total number of technology projects as elaborated by each firm in Graph 3.1 is, indeed, a sample from the population of technology projects that had actually taken place throughout the lifetime of a firm. Technology projects were derived from the interviews with the informants at each firm. As emphasized earlier, there is a recall issue about some of the projects that might have taken place. The earlier the implementation of a technology project, the more likely it is for the informant not to recall a project that actually might have taken place. Therefore, this sample may be biased and needs to be handled with extreme care when dealing with the frequency of technology projects. However, despite this caution, it is important to stress that, as explained earlier in Section 3.4.3, the firms are predominantly family-run enterprises with unbroken institutional memories greatly reduces this problem.

Therefore, in proposing the ‘technology project’ concept, I had one objective in mind. It would increase the number of observations and indeed allow for the data to be configured in the way that they could be used in econometric analyses. This concept itself is a major contribution to innovation systems analyses within a firm-centred approach. It is useful in finding and highlighting the details about each single interaction of firms and studying them in quantitative analyses, which would not be possible if the ‘firm’ were to be used as the unit of analysis.

3.4.7 'Knowledge Link': The Unit of Analysis

A 'knowledge link' is defined as kind of interaction between the firm and any one of the agents/partners in the system of innovation (including intra-firm sources) through which primarily knowledge is transferred to the firm by any means of technology transfer within a particular technology project. The domestic or foreign partner may be another firm or an institute in the form of a knowledge supplier. Knowledge links are attributes of technology projects; and there may be more than one knowledge link attached to a technology project. For instance, production of a new product in the firm might be conducted in a way that involved knowledge links with (i) a university department, (ii) a customer firm, and along with (iii) contributions from the firm's own R&D unit. In that particular case, there would be three knowledge links associated with the-one technology project. Therefore, within each technology project, information was sought about what technology was acquired and how through each of several 'knowledge links' involving different sources. There were between 1 and 5 actively used links per project, and the total of 289 technology projects provided a total of 408 observations of knowledge links (which formed the main database) that could be used in particular aspects of the analysis – not only about technology transfer and its impact on firms' capabilities, but also about aspects of the structure of the innovation system within which the firms were embedded. Firms are shown with their number of links in Graph 3.2.

Graph 3.2 Distribution of knowledge links by type of firm



Note: Firms are numbered according to the earliest year of establishment.
Source: Author's own data.

3.5 Dynamic Analysis: Introduction of a Time Pattern Involving Three Periods

One important aim of this research is to show changes in a system of innovation over time. Dealing with changes over time needs the introduction of a time pattern into the analysis. Considerable efforts have been made to derive a reliable time pattern for this research. Perhaps one of the most important contributions of the 'technology project' concept in this study has been its role in determining a time pattern for the analysis. The technology project is chosen as the unit to determine the time pattern, since its existence and evolution through successive projects paves the way for formation of linkages with other parties and a search for a possible emergence of an innovation system.

When determining the sub-periods for analysis in this research, two approaches have been considered:
i) Allocation of knowledge links between sub-periods as representative and explanatory as possible, and
ii) Periods taking historical events in Turkish economy into account.

Table 3.2 (in section 3.4.3 of this chapter) illustrates the allocation of knowledge links through 5-year periods. The largest number of links (240 links) appeared to have happened within the last five years. The least number of links arose during the first three 5-year intervals (27 links). However, as of 24 January 1980, the Turkish government went through radical changes in its whole economic policy and switched from import-substitution to export-orientation development policies. Changes also included deregulation of money and capital markets, and so on. This radical change influenced the governance of the economy from that date onwards. Therefore, allowing Sub-period I from 1967 to 1981 draws a line between two completely different economic policies applied in Turkey and captures this radical shift in the economy. Sub-period I is identified with the industrialisation strategies applied in Turkey towards import substitution.[16] It is characterised by several economic recessions of which the last

[16] During the application of import-substitution policies, the governments made considerable efforts towards creating the basis for the country to produce its own goods. It can be argued that these policies provided the ground for strengthening especially large firms in the key industries. Yet, for medium and small-sized firms, knowledge acquisition meant only the acquisition of machines. For instance, for a while in the mid 1970s, nearly all production of one medium-sized firm was devoted to glass fibre to be used in the first and only national car product, Anadol. In the related technology project, this firm had no

occurred in the late 1970s and some policy measures applied could not remedy the problems.

Impacts of the application of export-orientation policies in the industry after 1980, however, were felt with a time lag of approximately 10 years. It is the rather lagged influence of the passage to a market economy in 1980 that resulted in an increasing number of activities in firms, especially from 1989.

Another factor was the introduction of the Internet in the country from the mid 90s. Many firms in the private sector linked up with the Internet. This radical innovation caused firms instantly to be aware of recent changes and innovations in their field and adjust themselves accordingly. Thus, the 14-year sub-period from 1981 to 1996 is identified with a sense of an increasing number of firms and technology projects. There were shortfalls in 1992 and 1995 compared to previous years, but still a consistent overall growth can be observed (see Chapter 4 for explanations on the policy side).

The final sub-period lasts 5 years from 1997 to July 2001. There is an obvious emergence and progression of a larger number of firms and technology projects in this period. Yet, when the number of projects per firm is computed, they have a range of 1 to 3 and this does not change much between sub-periods. It would be preferable to have a significant rise in this indicator from Sub-period II to Sub-period III, which would provide a noteworthy clue for an emerging innovation system elsewhere. However, the increasing number of firms and increasing number of technology projects in total may well be an early sign of such an event. The distinguishing characteristics of the post-1981 and post-1997 periods allow the data to be analysed in three major sub-periods as shown in Table 3.4.

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foreign partners as expected. Moreover, it had only one domestic partner, namely the customer Anadol, from whom it received valuable feedback. No other domestic partners, such as a university, were listed related to this particular technology project during the interview. Basically, the firm transferred relevant process technologies from abroad in a previous technology project and based its production of glass fibre on this occasion in collaboration with its customer only. Glass fibre production in a developing country in the mid 1970s could be considered as a high-tech production activity. Should such a technology project take place at later stages, the firm would very likely be actively seeking knowledge from both other domestic and foreign agents. Eventually, the first and only completely Turkish design Anadol cars survived in the domestic market as the cheapest option for middle-income families: they were never improved as a product and gradually disappeared by not being able to compete with Renault and Fiat cars which entered the Turkish market as joint ventures with Turkish companies after the 1980s.

The international transfer of technology is conditioned by environmental constraints and opportunities, including the role played by the government (Contractor, 1998:321). However, as explained in section 3.3 of this chapter, effects of government policies on the emergence of an innovation system are not explicitly studied in this research because of the restrictions brought into the analysis. The three sub-periods, proposed as a policy-defined time pattern in this study, on the other hand, will provide a kind of basis to show the changes occurring over time with respect to policy changes applied by the governments.

Table 3.4 Length and characteristics of sub-periods used in this research

	Duration	Policy Characteristic	Technological Characteristics
Period I	1967-1981 (15 years)	Import-substitution	No links or only links related to machine and equipment acquisition to develop user skills only
Period II	1982-1996 (15 years)	Export-orientation	Links related to equipment acquisition and emergence of some basic collaborative agreements to develop mostly user and operational skills
Period III	1997-2001 (5 years)	Export-orientation	Increase in number of collaborative agreement type of activities aiming to develop replicative and adaptive skills

3.6 Key Concepts: Explaining the Variables and Their Categories

3.6.1 Variables of Technology Transfer and Technological Capability Analysis

This analysis relates the technology transfer concept to the technological capability concept. All the variables used in this analysis are link-specific and categorical.

3.6.1.1 Explanatory Variables

Three elements are used for analysing the technology transfer process. These are the existing knowledge base in the firm, the intensity of effort by the firm, and the mode of technology transfer. In this research, three variables are used to explain the existing knowledge base in the firm, four variables are used to explain the intensity of effort by the firm, and one variable is used for explaining the mode of technology transfer.

Existing Knowledge Base in the Firm

In this research, the *existing knowledge base* is defined as the already acquired stock capabilities held by the firm. As the first element of absorptive capacity of the firm, they refer to the level of its prior related knowledge (Cohen and Levinthal, 1990). In this research, as largely drawn from Kim (1998) and as explained in section 2.4 in the theory chapter, they aim to explain mainly the tacit component of capabilities embodied in human capital. They are identified as follows.

MANACD: *Manager qualifications related to education and academic research experience* and
MANIND: *Manager qualifications related to industrial experience*[17]
are intended to capture the importance of managerial influence on creating a knowledge base for the firm. Entrepreneurial leadership is an important factor that creates organizational conditions favourable for learning in the firm. Issues related to learning in the firm, such as the selection of technology to be acquired, gaining expertise in the technology already being used in the firm and the ability to solve existing problems with the technology used, are much related to the managerial knowledge base, especially in small and medium-sized firms.

PRES: *Percentage of researchers and engineers in total employees*[18]
is used to measure the amount of skilled labour in the firm where the tacit knowledge is embodied.

The variables for existing capabilities of the firm and their categories as emerging from the answers to the related questions in the Interview Questions (see Appendix B) are shown in Table 3.5.

[17] Data for these variables are mainly formed from the answers given to Questions 21 and 22 in Part 3 in the Interview Questions (see Appendix B).
[18] Data for this variable are mainly formed from the answers given to Question 23 in Part 3 in the Interview Questions (see Appendix B).

Table 3.5 Variables and their categories for existing capabilities of the firm

Name of variable	Categories for the variable
Manager qualifications related to education and academic research experience (MANACD)	Degree from a national university Degree from a university abroad No academic degree
Manager qualifications related to industrial work experience (MANIND)	Work experience at a domestic firm Work experience at a firm abroad No work experience in the field
Percentage of researchers and engineers in all employees (PRES)	more than 50% less than 49%

Intensity of Effort by the Firm

Intensity of effort is defined as the firm's efforts towards internalisation of knowledge acquired from the technology transfer process. It is the second major element of the absorptive capacity of a firm. It aims to explain the commitments of the firm towards continuous knowledge acquisition and creation as explained in Cohen and Levinthal (1990). Such commitment needs concrete acts to prove to be successful. As explained in section 2.4 above and drawn from Kim (1998), these may include issues related to preparatory measures prior to acquisition of technology, labour mobility, R&D and design. Four variables are used to explain intensity of effort by the firm.

SECONT: *Search into contributor* and
SETECH: *Search into technology to be acquired from the contributor*[19]
are pre-project activities in the form of preparatory efforts undertaken by the firm to find out what kind of product or process technology they will transfer from domestic or foreign contributors and what kind of domestic or foreign contributor they will deal with. The answers to interview questions are aggregated to provide a generalised understanding of complicated situations. *Search into contributor* is considered as simple when the knowledge gathered about the contributor is mostly via Internet search or via activities such as attendance in conferences, fairs and exhibitions, where the level of knowledge needed is relatively lower. It is considered to be experience-based if the firm gathered the information about the contributor from other parties that had collaborations

[19] Data for these variables are mainly formed from the answers given to Questions 47, 48 and 49 in Part 3 in the Interview Questions (see Appendix B).

with this particular contributor in the past or if the firm contacted a continuously knowledge-seeking institution such as a university or research institute to get information about the contributor. Similarly, s*earch into technology* is considered as simple search when the information gathered is mostly via Internet search, journals and product leaflets, visits to the technology supplier firm, or only a price comparison with substitutes for the technology. It is considered to be knowledge-based and deep if the firm contacted especially the provider of the technology or another knowledge holding body about this particular technology to get information about the technology to be acquired. This knowledge-based research provides the firm with tacit knowledge embodied in human beings.

RND: *R&D activities*[20]

stands for the firm's efforts put into research activities with regard to each link. Such activities differ in application. For instance, a firm may have its own R&D unit on its premises and be primarily engaged in research activities related to the project. Or, it may take active part in research activities related to the project by using one of the partner's laboratories. Or, R&D conducted elsewhere (mostly in the headquarters of a foreign firm) may find application on the firm's premises. However, in the latter case, there is no R&D activity that the firm is somehow involved in, related to the project. Therefore, R&D conducted primarily by the firm in its own R&D unit is categorised as 'primary' R&D; R&D conducted at the partner's premises where the firm takes an active role is categorised as 'active' R&D; and finally if there is no R&D conducted in the project, category 'none' applies (see Table 3.6).

DESIGN: *Design activities*[21]

stands for the firm's efforts put into design activities with regard to each link. These activities differ in content and level. The firm's design activities may solely rely on a customer's recipe. Or, the firm may be creative and achieved the level of capability to originate its own designs. The former is categorised as 'trivial and none', denoting the low level of significance in the firm's design capabilities. The latter is categorised as

[20] Data for this variable are mainly formed from the answers given to Questions 24, 25 and 26 in Part 3 in the Interview Questions (see Appendix B).
[21] Data for this variable are mainly formed from the answers given to Question 27 in Part 3 in the Interview Questions (see Appendix B).

'non-trivial', pointing a high level of significance in design capabilities. The variables for intensity of effort by the firm and their categories are shown in Table 3.6.

Table 3.6 Variables and their categories for intensity of effort by the firm

Name of variable	Categories for the variable
Search into contributor (SECONT)	experience-based simple and none
Search into technology to be received from contributor (SETECH)	knowledge-based simple and none
R&D activities (RND)	primary active none
Design activities (DESIGN)	non-trivial trivial and none

Mode of Technology Transfer

This variable[22] is used in this research to examine whether the transfer mode of technology has any direct impacts on the increments in capability at the firm level. In the interview questions, the firms were asked about the means of acquisition of current core production technology in use as well as the previous kinds. The means of collaboration with partners in a particular technology project were also identified. The observed technology transfer channels are shown in Table 3.7 as classified according to their organizational context. This is described in detail in Chapter 2 in section 2.3.

[22] Data for this variable are mainly formed from the answers given to Questions 45, 52 and 53 in Part 3 in the Interview Questions (see Appendix B).

Table 3.7 The variable *Mode of Technology Transfer* (TECHTRANS) and its categories

Categories of the variable 'Mode of Technology Transfer'	**Elaborations to the categories of the variable**
External: Arm's length activities	import of machinery and capital goods licence agreement with import of machinery licence agreement with import of machinery & know-how know-how transfer journals, databases, patent disclosures, internet search firm visit, conferences, fairs and exhibitions inter-firm marketing alliance exporting turnkey agreements subcontracting: outward processing
External: Collaborative agreements	inter-firm marketing alliance with knowledge inflow from technology supplier subcontracting: original equipment manufacture and direct offset consultancy external problem-solving activity technical assistance and co-operation customer-oriented product development inter-firm strategic technology alliances firm-research institute technology partnering firm-university technology partnering
External: Foreign Direct Investment	joint ventures subsidiaries brain gain and re-gain
Internal: Firm-endogenous activities	in-house problem-solving activity reverse engineering in-house R&D project

Initially, modes of technology transfer are categorized as external and internal. Technology projects with external acquisition modes always required involvement of a partner in the project, such as a university, research institute, and another firm or technology supplier. External modes of technology transfer are further divided into three: (i) Arm's length activities, where the knowledge acquired is mostly codified and uni-directional from the supplier to the firm; (ii) Collaborative agreements, where the knowledge acquired is mostly from person to person, having a bi-directional character between the partners; and (iii) Foreign Direct Investment, where knowledge is acquired via equity-based interactions and brain gain.

In addition, it was observed that technology projects with internal acquisition modes originated mostly from the initiative of the manager/engineer of the firm. Therefore, the latter are endogenous to the firm, with the firm's engineers taking the leading role, although accompanied by external partners in most of the cases. The frequency of firm-endogenous activities amounted to such a considerable number that they could not be neglected in this research. This approach also paves the way for understanding the significance of the firm's own knowledge endowments to pursue technology projects and to create new knowledge. Activities classified under this heading are in-house problem-solving activity, reverse-engineering and in-house R&D projects. These firm-endogenous activities should be well differentiated from the variable *R&D activities.* Regarding the former, R&D is not necessarily a part of these activities, even though in-house R&D projects are a part of it. Also, R&D generally is a part of the collaborative agreement type of activities as well. Therefore, these two R&D related components do not overlap with each other.

3.6.1.2 Dependent Variable: Increment in Capability (INCCAP)

Increment in Capability serves to examine the role of technological capability in the capability analysis. It is a link-specific, categorical dependent variable. It is inspired by Lall's (1992: 167) categorization of technological capability levels as described in section 2.4.3 of Chapter 2.

How the variable *Increment in Capability* is formed ought to be thoroughly explained. Understandably, asking firms directly about the level of the capability they achieved through their links would not be a reliable approach. Instead, links were assessed for their outcomes, in the form of increments to their existing level of capability related to each technology project. Each project added some more knowledge to the prior knowledge of the firm compared to the previous project. In parts of the interview questionnaire, questions[23] regarding the technology transfer and its extensions or renewals, and about the interactions of the firm were asked. During the course of semi-structured interviews, while firms gave information they also revealed the outcomes from their links, whether it were operation of a technology, improvement of a technology or a new product. These are identified as increments to the current capability of the firm, and the outcomes were listed. Thus, this proxy is purposefully used to comment on and decide upon the increment of technological capability achieved as a consequence of interaction between the firm and an institution or another firm. As shown in Table 3.8 observations related to these outcomes are classified depending on

[23] Data for this variable are formed from the answers given to Questions 51, 54, 55 and 56 in Part 3 in the Interview Questions (see Appendix B).

Lall's (1992) categorization of technological capabilities to derive the variable *Increment in Capability* to be used throughout this research.

Lall (1992: 167) provides a sophisticated classification for basic, intermediate and advanced technological capabilities. Each level of capabilities is further categorized according to their relations with pre-investment, project execution, process engineering, product engineering and linkages within the economy. However, Lall's classification of capabilities related to pre-investment, project execution and linkages are not included within the focussed scope of this research. Only capabilities related to process and product engineering are considered.

The variable *Increment in Capability* has three categories: (i) Additional competence for process operation, (ii) Additional competence for improvement of process or product technology, and (iii) Additional competence for development of process or product technology. Initial and low levels of increments in capability concentrating on the basic use of processes and products are put into the category of operational capability for process technology. Increments of intermediate level capabilities are categorized under improvements in processes and products. For instance, these consist of additional competence to undertake low-tech process development, and modification of an acquired process by contributions from the firm's engineers enrolled in postgraduate programmes of a domestic university or recruitment of skilled labour. Kim (1997a: 341) also notes that Korean science-based firms, with the assistance of domestic universities or smaller foreign firms, can build sufficient capability to crack technology through advanced reverse-engineering (in contrast to simple reverse-engineering of low technology), though mature technology firms with insufficient capability could not progress further in this case. Finally, additional competences towards higher technology process and product design, modification and development are regarded as proofs of development of process or product technology (see Table 3.8).

Table 3.8 The variable *Increment in Capability* (INCCAP) and elaborations to its categories

Lall's categorization of technological capabilities related to process and product engineering only	**Adaptation of observations from this research to Lall's categorization as increments with respect to the previous technology project**
BASIC CAPABILITIES (Simple-Routine-Experience based) a) related to process engineering: Debugging, balancing, quality control preventive maintenance, assimilation of process technology b) related to product engineering: Assimilation of product design, minor adaptation to market needs	**Additional competence for operation of process or product technology** a) related to process engineering: Transfer of machinery, equipment and know-how only with respect to low-tech, medium-tech and state-of-the-art processes during firm establishment and later, process operation, enhanced process operation, process troubleshooting, etc. b) related to product engineering: Knowledge acquisition of new products and their uses, product introduction to foreign markets
INTERMEDIATE CAPABILITIES (Adaptive-Duplicative-Search based) a) related to process engineering: Equipment stretching, process adaptation and cost saving, licensing new technology b) related to product engineering: Product quality improvement, licensing and assimilating new imported product technology	**Additional competence for improvement of process or product technology** a) related to process engineering: Additional competence to undertake low-tech process development, modification of acquired process by contribution from the firm's engineers enrolled in postgraduate programs of domestic university or from recruitment of skilled labour, capability to use complex quality control machine and to interpret test results b) related to product engineering: Acquisition of know-how only with respect to state-of-the-art product, quality control equipment, competence to create improved product
ADVANCED CAPABILITIES (Innovative-Risky-Research based) a) related to process engineering: In-house process innovation, basic research b) related to product engineering: In-house product innovation, basic research	**Additional competence for development of process or product technology** c) related to process engineering: Additional competence to undertake own high-tech process technology development, electronic equipment design for own process technology, software design for own process technology, design of own process technology d) related to product engineering: Additional competence to create a new product (for the firm or domestic market)

In addition to the categories elaborated here, a fourth observation for the case of 'no additional capability acquired' emerged during the course of face-to-face interviews in this research. Such observations amount to 7% of the total observations in the whole dataset. This category is combined with 'increment in operational capability' category for ease of use in the econometric analyses (see Table 3.9 in Section 3.6.3). The dependent variable with more than three categories caused some statistical problems in the multinomial logistic regressions, which could only be overcome by merging the categories of the variable. Also, as Hosmer and Lemeshow (2000: 260) state, the details of the model are most easily illustrated with three categories. Further generalization to more than three categories is a problem more of notation than of concept.

3.6.2 Variables of Technological Capabilities and Systems of Innovation Analysis

This analysis relates the technological capability concept to the innovation systems concept. The variables used in the descriptive parts of this analysis are categorical and link-specific. These variables are re-arranged in another dataset to be used in the linear regression analyses. They are numeric and link-specific.

3.6.2.1 Explanatory Variable: Increment in Capability (INCCAP)

The variable *Increment in Capability* is used to assess the role of technological capability accumulation in the technological capability and innovation system analysis. Whilst this variable was a dependent variable in the technology transfer and technological capability analysis, it represents an explanatory variable in this analysis. It is constructed with the same categories (see Table 3.8).

3.6.2.2 Dependent Variables

Three variables stand for analysing the concept of innovation systems. These are origin of link (i.e. foreign or domestic), type of source (i.e. firm, institute or intra-firm source) and density of the system.[24]

Origin of Link

This variable aims to capture the linkage characteristics of the system in the particular sector of materials in this research, whether there is a dominance of domestic linkages and the system is more inclined to be a national one, or rather of foreign linkages, providing a basis for a more international technological system or a sectoral system.

In the regression analyses in Chapter 6, following frequency and cross-classification analyses, each category of the variable 'origin of link' is regarded as a separate variable (see section 3.7.3 in this chapter).

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[24] Data for these variables are mainly formed from the answers given to Questions in Part 4 in the Interview Questions (see Appendix B).

Type of Knowledge Source

This variable aims to capture the system characteristics of firm interactions, initially differentiating between firm-firm interactions and firm-university or research institute interactions.[25] Then, further data exploration is by breaking down the type of source data by origin of link, whether the interaction is with a foreign or domestic firm and foreign or domestic institute. Other firms interacted with are observed as other rival firms operating in the same field, process technology supplier firms, raw material supplier firms, component and systems producer firms from domestic or foreign environment.

In addition to these, during the interviews with the firms, a third form of 'self' linkage emerged along with firm and institute links. It was observed that there are considerable amount of activities undertaken in the firm using its own in-house sources. These amounted to a considerable proportion of all linkages (16.7%). They were initiated within the firm, usually with the initiative of the manager or an engineer in the firm. These activities might solely rely on the firm's engineer(s) or sometimes be further supported by other external partners at different points of a technology project. They are called 'intra-firm sources' in this study. In most discussion in the systems of innovation literature, such activities would not be included in the analysis of the concept. Interactions between the actors of the system and outsourcing knowledge would be the main concern. Edquist (2002:4) points out that firms need to interact with each other and other organizations in order to innovate. Yet, he also states one major weakness of innovation systems approach as neglecting organisational and individual learning in the firm (Edquist, 2001:3). Even though not exactly introduced within the innovation systems approach, but within the context of technological learning, Kim (1997: 91) stresses the sources of technological learning as the 'international community, domestic community and in-house efforts at the firm level'. In-house efforts are vital for internal digestion of the knowledge acquired from external sources. Therefore, practically, it would be inappropriate to exclude intra-firm sources from this study.

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[25] In this study, 'institutions' will be regarded as 'organisations'. These are 'formal structures with an explicit purpose' or what are normally called organisations as described in Nelson and Rosenberg (1993) and not 'things that pattern behaviour' like norms, rules and laws as described in Lundvall (1992). Therefore, organisations in the 'institution' concept in this research are narrowed down to represent the universities, national research institutes and private research institutes that pursue R&D activities.

Because such activities are expected to contribute immensely to capability accumulation, which in turn influences networking in the innovation system, they are deliberately classified as the third category of the type of source. However, they are examined separately from firm and institute linkages.

In the regression analyses in Chapter 6, following frequency and cross-classification analyses, each category of the variable ‘type of source’ is regarded as a separate variable (see section 3.7.3 in this chapter).

Density of Links

Systems are usually defined by the volume and characteristics of the linkages that bind them together (Archibugi et al., 1999: 531). The volume of interactions is important in a system in order to characterise whether it is a vibrant or inert system. The ‘density of links’ variable, used in this research, is constructed as ‘links per firm per year’.

3.6.3 Summary of Variables in This Research

This research aims to provide an explanation of increments in firm-level technological capabilities by the transfer of technology process in the materials industry in Turkey and by this interaction leading to the emergence of an innovation system in this particular industry. The research is designed to be analysed at two levels, comprising a firm-level analysis and an industry-level analysis using the variables shown in Table 3.9.

Table 3.9 Summary explanations for variables of this research

Variable	Description of the Variable	Type of Variable	Categories of the Variable
STAGE I. Technology transfer and technological capability analysis			
INCCAP	Increments in Capability (with regard to the previous project)	categorical dependent	Development of product or process technology Improvement of product or process technology Operational capability or no capability acquired
TECHTRANS	Mode of technology transfer	categorical explanatory	Arm's length activity Collaborative agreements Firm-endogenous activity Foreign direct investment
Variables for Existing Capabilities of the Firm			
MANACD	Manager qualifications related to education and academic research experience	categorical explanatory	Degree from a national university Degree from a university abroad No academic degree
MANIND	Manager qualifications related to industrial experience	categorical explanatory	Work experience at a domestic firm Work experience at a firm abroad No work experience in the field
PRES	Percentage of researchers and engineers	categorical explanatory	more than 50% less than 49%
Variables for Intensity of Effort by the Firm			
SECONT	Search into contributor	categorical explanatory	experience-based search simple or none
SETECH	Search into technology to be acquired from contributor	categorical explanatory	knowledge-based search simple or none
RND	Existence of R&D unit	categorical explanatory	primary active none
DESIGN	Existence of design activities	categorical explanatory	non-trivial trivial or none
STAGE II. Technological capability and innovation system analysis			
ORGLINK	Origin of link	categorical numeric dependent	foreign domestic
SOURCE	Type of source in the system	categorical numeric dependent	firm (foreign firm, domestic firm) institute (foreign institute, domestic institute) intra-firm sources
DENSITY	Density of links in the system	numeric dependent	Number of links per firm per year
INCCAP	Increments in Capability (with regard to the previous project)	numeric explanatory	Development of product or process technology Improvement of product or process technology Operational capability or no capability acquired

3.7 Data Analysis

The ultimate aim of data analysis is to draw conclusions based on generalisations from the data acquired, as framed by the proposed research questions. From the start of this study, the analysis of the data has aimed to use statistical methods rather than qualitative methods. Thus, each step of the research was designed according to this goal, starting with the design of the questions asked in the firm interviews for data configuration and processing. The reason for opting for more favourable statistical analysis methods is that they provide reliable and robust conclusions, whilst qualitative analyses of firm case studies could yield results with a tendency to considerable inescapable subjectivity, not allowing for generalisations and maybe leading to excessive success stories about the firm analysed. Most importantly in this thesis, using statistical and econometric methods based on qualitative categorical data allows for deriving generalisations for the industry. Moreover, during the interviews, particularly the science-based activity firms opted for withholding their company names. Statistical analysis approach would be better suited to the requests of these firms as well, preserving the firms' confidentiality.

Both analyses chapters of this thesis (Chapter 5 on Technological Capability Analysis and Chapter 6 for Innovation System Analysis) start with sections of data illustration, where frequency analysis is used to depict the data. Then, cross-tabulation analyses follow to explore the relationship between the dependent and independent variables initially. Each cross-tabulation is complemented with Pearson chi-square tests. Econometric analyses are then applied to look for the strength and direction of the relationships to be examined.

In summary, the exploration of the relationships to be examined in this research is based on the following approaches to data analysis:

- by cross-sectional analysis involving the pooled data covering the two segments of the industry and all time periods;
- by cross-sectional data analysis for each of the industry segments separately;
- by examining within each segment changes over time in the key variables and their relationship.

3.7.1 Data Configuration

The *primary set of data* used in the capability analysis is categorical/nominal (each cell in the dataset representing one knowledge link, in total 408 links[26]). A *categorical* variable is one for which the measurement scale consists of a set of categories. Categorical variables are called *nominal* if their levels are not ordered[27] (Agresti, 1990: 2). For instance, the variable 'increment in capability' is a categorical/nominal dependent variable (the categories being increment in operational capability or no capability; increment in improvement capability of product or process technology; increment in development capability of product or process technology). Such variables with categories without an order are sometimes called choice variables.[28]

In Chapter 6, analysis of the innovation system partly uses the primary dataset (for descriptive analyses) and partly uses a numeric dataset derived from the primary dataset (for the econometric analyses). The primary dataset with 408 observations is transformed into a new firm-specific dataset with 228 observations by re-arranging (adding up) the number of links for each category of the variables of the primary dataset for each firm for three-year intervals. By this way, a smaller range of a numeric (not categorical any more as was the case for the primary dataset) pooled dataset is obtained for the linkages of 19 firms in the sample for the total period of 1967 to 2001 arranged in three-yearly intervals. What was the category of a variable in the primary dataset

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[26] The procedure for obtaining 408 links of the primary data set was explained in sections 3.4.6 and 3.4.7 of this chapter.

[27] By ordered variable it "…is meant that the outcome associated with a higher value of the variable Y_i is *ranked higher* than the outcome associated with a lower value of the variable" (Borooah, 2002: 5). An example of categorical/ordered variable would be likely to have outcomes inherently ordered as "low, medium, high" or "unimportant, important, very important".

[28] The selection of the method of analysis is closely associated with the nature of the dependent variable – i.e. ordered or choice, in logistic regression analysis. If the dependent variable is a choice/nonordered variable, then the appropriate method would be Multinomial Logistic regression; whereas if it is an ordered variable, then Ordered Logistic Regression would be appropriate. However, sometimes it might not be that easy to decide upon whether the dependent variable is ordered or choice variable. In such cases of uncertainty, (where I faced here in this analysis, because the variable INCCAP is not inherently ordered like "low, medium, high") "a sensible rule might be to regard it as nonordered, as corollary, to estimate models using it as dependent variable by the methods of multinomial logit. This rule is sensible because treating an outcome variable as ordered, when in fact it is nonordered, imposes a ranking on the outcomes that they do not possess and invokes the restrictive assumption of parallel slopes, which is likely to bias the estimates. On the other hand, not treating an outcome variable as ordered, when in fact it is ordered, fails to impose a legitimate ranking on the outcomes. This omission may lead to a loss of efficiency, but it is unlikely to bias the estimates. In the face of these two possible errors, the loss of efficiency a less serious error to make than that of biased estimates." (Borooah, 2002: 6-7). Therefore, when deciding upon the method of quantitative analysis (see section 3.7.3.1) this point has been taken into consideration.

became an individual variable in the new dataset (e.g. 'origin of link' is a variable in the primary dataset with its categories foreign link and domestic link; each category is a single variable in the new dataset).

3.7.2 Data Considerations for Cross-Tabulation Analyses

Cross-tabulations (or contingency tables) display the individual relationship between two variables. Both technology transfer and technological capability analyses in Chapter 5 and the innovation system analysis in Chapter 6 use the primary dataset for cross-tabulation analyses. The technology transfer and technological capability analyses search for the association between the dependent variable 'increment in capability at time t' and the explanatory variables (pertaining to the existing knowledge base and intensity of effort in the firm) also at time t. Therefore, I used the measures at time t for all variables for investigating the effect of knowledge acquisition methods on technological capability accumulation. The former is expected to influence the latter with an immediate effect. However, the technological capability and innovation system analyses in Chapter 6 focus on the relation between the capability level that the firm has already and where it sources its technology from. Therefore, using the 'increment in capability' as a lagged variable in the analysis would prevent errors in this analysis. Furthermore, using past increments in capability as a proxy for stock capability levels is thought to be suitable for the aim of analysis in Chapter 6. So, in Chapter 6, 'increment in capability at time t-2'[29] is used as a proxy for level of stock capability at time t.

3.7.3 Econometric Analyses

Statistical methods have been major tools in economics to estimate economic relationships from data. Among them, regression methods are widely used in data analysis to explain the relationship between a dependent variable and a number of independent variables. There are different types of regression methods depending on the type of data to be used in the analysis.

The statistical methods to be applied should be appropriate for the conditions of the data. Several statistical methods[30] could be applied in this research, which could comply

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[29] It is thought that 2 years rather than 1 year would be a more appropriate time span for the firm to learn from its links and accumulate the knowledge acquired.
[30] In all the statistical analysis, SPSS- Statistical Package for Social Scientists is used.

with the above conditions of the data. Statisticians developed different kinds of regression analyses for 'categorical responses to meet the need for analyses of multivariate discrete datasets' (Agresti, 1990:1).

For the technology transfer and technological capability analysis, the Multinomial Logistic Regression Model could be a way to understand the existence and strength of relationships between the categorical variables of the primary dataset. Binary Logistic Regression or Linear Regression models could not be employed in this analysis simply because both dependent and independent variables are categorical. With binary logistic regression the dependent variable needs to be arranged as a categorical variable with only 2 categories and the independent variables need to be numeric. Linear regression needs all dependent variables to be numeric.

For the technological capability and the innovation system analysis, Linear Regression Models could explain the existence and strength of relationships between numeric transformed variables of a second dataset derived from the primary dataset. Now that the dataset is bound by numeric variables, one cannot employ either multinomial or binary logistic regression models, since they necessitate use of categorical variables. The latter two models could not be employed in this analysis using the primary dataset, either. The second dataset does not allow the use of binary logistic regression model, which necessitates a categorical dependent variable. One might think that another set of multinomial logistic regression models could be applied to the primary dataset for the innovation system analysis, however the dependent variables in that case would not have 3 or more categories.

The design of all research questions of the thesis, indeed, also traces changes in the variables over time. The selected statistical methods should thus also be able to serve this objective as well.

3.7.3.1 Estimation Method for Technology Transfer and Technological Capability Analysis: Multinomial Logistic Regression

For the technology transfer and technological capability analysis, multinomial logistic regression is selected as the method of analysis in this research. The dependent variable of a logistic regression model is nominal with two or more categories. It is called a binary logistic regression model when the dependent variable is nominal with two categories. It is called a multinomial logistic regression model when the dependent variable is nominal with more than two categories. The model also allows for the explanatory variables to be nominal with several categories as is the case in this study. As stressed earlier, the measurement scale is important when a regression model for a discrete dependent variable with more than two responses is considered (Hosmer and Lemeshow, 2000: 261). The dependent variable may be measured in nominal or ordinal scale, and thus the regression method changes depending on this. In this thesis, the dependent variable is measured on a nominal scale.

In a multinomial logistic regression, assuming that the categories of the dependent variable, Y, are coded as 0, 1 and 2; a three-category dependent variable model needs two logit functions. When one of the categories of the dependent variable is taken as the 'base category' (i.e. Y=0), two logit functions are formed comparing Y=1 and Y=2 to it (Hosmer and Lemeshow, 2000:261). The outcome Y=0 is referred to as the 'base category'. "The coefficients of this outcome are set to zero and the risk-ratios of other outcomes are defined with respect to the probability of this base outcome" (Borooah, 2002: 55).

Assuming that there are *p* independent variables and a constant term, denoted by the vector, **x**, of length $p+1$ where $x_0 = 1$, Hosmer and Lemeshow (2000:261) denote the two logit functions for a multinomial logistic regression as follows:[31]

Equation 3.1

$$g_1(x) = \ln [\text{Prob}(Y=1/x)/\text{Prob}(Y=0/x)] = \beta_{10} + \beta_{11}x_1 + \beta_{12}x_2 + \ldots + \beta_{1p}x_p = \mathbf{x}'\,\boldsymbol{\beta}_1$$

Equation 3.2

$$g_2(x) = \ln [\text{Prob}(Y=2/x)/\text{Prob}(Y=0/x)] = \beta_{20} + \beta_{21}x_1 + \beta_{22}x_2 + \ldots + \beta_{2p}x_p = \mathbf{x}'\,\boldsymbol{\beta}_2$$

As Borooah (2002:48-9) points out, in the multinomial logistic regression model, "the risk-ratio should be distinguished from the *odds-ratio* where the latter refers to probability of an outcome divided by 1 minus the probability of that outcome. In a binary logistic regression model, there is no distinction between the risk-ratio and the

[31] For a complete mathematical derivation of a multinomial logistic regression model based on three-category dependent variable, see Hosmer and Lemeshow (2000:261-4).

odds-ratio since the base outcome Y=0 is simply the outcome Y≠1. In a model with more than two possible outcomes, the outcomes Y=0 and Y≠1 are different. Therefore, in multinomial logistic regression models, results are expressed in terms of *risk-ratios* and not in terms of odd-ratios since these are now different from each other. So, the ratio of the probability of outcome Y=*m* to that of Y=*k*, or [Prob(Y = *m*)/ Prob(Y = *k*)] is called *risk-ratio*. The multinomial logistic regression technique estimates the influence of independent variables on the logarithm of the *risk-ratio*."

On the basis of the variables described in the above sections of 3.6.1 the log risk-ratio (that is the logarithm of ratio of the probability of outcome Y=j to that of outcome Y=1) of three separate models were specified as follows in the econometric analyses in Chapter 5.

Model 3.1 assessing the effect of technology transfer mode on capability increments:

$$\text{Log}\,[\Pr(\text{INCCAP=j})/\Pr(\text{INCCAP=1})] = \alpha_0 + \alpha_1\text{TECHTRANS} + \alpha_2\text{DFIRM} + \alpha_3\text{TECHTRANS*DFIRM} + \varepsilon_{ij}$$

where INCCAP=increment in capability
TECHTRANS= mode of technology transfer
DFIRM= dummy for science-based technology firm

Model 3.2 assessing the effect of existing knowledge base of the firm on capability increments:

$$\text{Log}\,[\Pr(\text{INCCAP=j})/\Pr(\text{INCCAP=1})] = \beta_0 + \beta_1\text{PRES} + \beta_2\text{MANACD} + \beta_3\text{MANIND} + \beta_4\text{DFIRM} + \beta_5\text{PRES*DFIRM} + \beta_6\text{MANACD*DFIRM} + \beta_7\text{MANIND*DFIRM} + \varepsilon_{ij}$$

where INCCAP=increment in capability
PRES=percentage of researchers/engineers to total employees in the firm
MANACD=manager specifications related to academic and research experiences
MANIND= manager specifications related to industrial and work experiences
DFIRM= dummy for science-based technology firm

Model 3.3 assessing the effect of intensity of effort of the firm on capability increments:

$$\text{Log}\,[\Pr(\text{INCCAP=j})/\Pr(\text{INCCAP=1})] = \delta_0 + \delta_1\text{RND} + \delta_2\text{DESIGN} + \delta_3\text{DFIRM}$$

$$+ \delta_4 RND*DFIRM + \delta_5 DESIGN*DFIRM + \varepsilon_{ij}$$

where INCCAP=increment in capability
RND=R&D activities
DESIGN=design activities
DFIRM= dummy for science-based technology firm

3.7.3.2 Estimation Method for Technological Capability and Innovation System Analysis: Linear Regression Models

For the technological capability and the system of innovation analysis, linear regression is selected as the method of analysis in this research. The changes and differences in system characteristics can best be explained by firm-specific data, as is always argued in this thesis. The main dataset used in the analyses in Chapter 5 and in section 6.2 of Chapter 6 is arranged with a firm-centred approach. However, being categorical this dataset does not allow for regression analyses. Therefore, it needs to be smoothly transformed into a new firm-centred and numeric dataset as explained in section 3.7.2 of this chapter.

Using the variables of the new dataset (which now forms a numeric dataset with 228 observations and 13 variables – 3 explanatory and 10 dependent variables) sets of linear regressions are conducted. The regression analysis can tell us how significantly or insignificantly an explanatory variable can influence the dependent variable. In this part of the research, I am looking at the influence of increments in technological capabilities from the technology transfer process on the emergence and the elements of the system of innovation in the particular industry in concern. Since there are three different technological capability levels in the new dataset, each of them will be individually regressed against the dependent variables to find out their effects on the innovation system. Also, the expected relationship between system characteristics and the capability increments implies a time lag. Capability increments in one period may influence the structure of the system in a later period. Therefore, variables are constructed to represent time-lagged capability increments in the models.

Along with the influence of the capability increments, I am also interested in the influence of type of firm and the effect of time period – especially the last five years of the research from 1997 to 2001[32] on the innovation system. Therefore, two dummy variables representing the above two will be introduced into the models.

Based on the ideas above, the regression models are formed as below.

Model 3.4 assessing the effect of technological capability increments on the origin of link

Foreignlink = $\alpha_0 + \alpha_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or*
(Domesticlink) INCCAPdevelopment$_t$ + α_2INCCAPoperational$_{t-1}$ *or*
INCCAPimprovement$_{t-1}$ *or* INCCAPdevelopment$_{t-1}$
+ $\alpha_3$dummyfirm + $\alpha_4$dummyperiod$_{1997-2001}$ + u

Model 3.5 assessing the effect of technological capability increments on the type of knowledge source in the system

Firm = $\beta_0 + \beta_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or*
(Institute) INCCAPdevelopment$_t$ + β_2INCCAPoperational$_{t-1}$ *or*
(Intrafirmsource) INCCAPimprovement$_{t-1}$ *or* INCCAPdevelopment$_{t-1}$ +
$\beta_3$dummyfirm + $\beta_4$dummyperiod$_{1997-2001}$ + u

Model 3.6 assessing the effect of technological capability increments on the type of knowledge source differentiating between origin of link

Foreignfirm = $\delta_0 + \delta_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or*
(Foreigninstitute) INCCAPdevelopment$_t$ + δ_2INCCAPoperational$_{t-1}$ *or*
(Domesticfirm) INCCAPimprovement$_{t-1}$ *or* INCCAPdevelopment$_{t-1}$
(Domesticinstitute) + $\delta_3$dummyfirm + $\delta_4$dummyperiod$_{1997-2001}$ + u

Model 3.7 assessing the effect of technological capability increments on the density of links

Linkdensity = $\gamma_0 + \gamma_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or*

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[32] The density of links per firm per year increased noticeably only in the third period (1997-2001). The first period (1967- 1981) and the second period (1982-1996) show similar patterns for density of links (see Table 6.5). Thus, I shall check for the effect of the last period only on the elements of the innovation system and regard the first two periods as a single period in the regression analyses. This approach will also be helpful in eliminating the concerns for collinearity between period dummies if two period dummies were to be introduced into the models.

$INCCAPdevelopment_t + \gamma_2 INCCAPoperational_{t-1}$ *or* $INCCAPimprovement_{t-1}$ *or* $INCCAPdevelopment_{t-1} + \gamma_3 dummyfirm + \gamma_4 dummyperiod_{1997\text{-}2001} + u$

3.8 Conclusion

This chapter has explained the methodology that is used to answer the research questions. First, the research questions were introduced. Secondly, the research design, the rationale for selecting the materials industry, the sample of the firms used in the analyses, data acquisition methods and the unit of analysis in this research were described. Thirdly, the key concepts were introduced and explained. Lastly, the statistical methods that are used to analyse the empirical data were described, followed by the introduction of econometric models, which form the basis of the analyses in the following Chapters 5 and 6.

CHAPTER 4 THE TURKISH ECONOMY AND INNOVATION SYSTEM

4.1 Introduction

The objectives of this chapter are threefold. First, the general context of the structure of Turkish economy, industry, growth and trade will be presented. Second, this first part will be extended into an understanding about the role of 'higher technology' industry in Turkey's industrial structure and hence about the importance of the specific cases of this thesis. Third, the key issues about the features of the 'innovation system' in Turkey will be provided. This discussion will particularly consist of: (i) the paths and patterns of industrial technology development in Turkey, (ii) the main system actors and their roles and how these have changed, (iii) the main system interactions and the associated problems and whether and how these have changed, and finally (iv) the main issues arising and what is known or not known about these main issues and why.

4.2 General Overview of the Turkish Economy: Structure, Growth and Trade

The Turkish economy experienced two different stages in the past. From the foundation of the Republic in 1923 until 1980, import-substitution policies underpinned the industrialisation process. In 1980, with drastic changes, liberalisation in macroeconomic policies and export-orientation policies took over. The post-1980 period itself may be split into two sub-periods: the sub-period from 1980 to 1997 and that from 1997 onwards. This whole period was characterised by the impacts of the application of deregulation in the economy (and export-orientation policies in the industry). It took some years for the economy effectively to perceive and absorb the changes and establish the background for a new system. If the economy had not suffered from macroeconomic ups and downs and crises during these years; the adjustment could have been faster. The sub-period from 1997 to 2001 is identified with some recognition of required reforms in the Turkish economy at the state level. The decisions about the ongoing structural reforms currently in Turkey were set mostly in 1997. These included reforms and changes in social security system, state-owned enterprises and their privatisation (OECD, 1997), arrangements in the financial system including the Central Bank's independence, etc. At present, the successful application of these reforms has created favourable conditions for basic indicators such as the inflation rate, interest rate, growth rate, etc., in the Turkish economy.

4.2.1 The Pre-1980 Period

4.2.1.1 Industry and Growth

From 1923 till the 1950s, the Turkish economy mainly relied on the agricultural sector. Yet the major enterprises in the fields of mining and manufacturing[33] were established in this period by the initiative of the state, pursuing development policies based on industrialisation. However, only after 1950s did the non-agricultural sectors, mainly services, mining and manufacturing, start to grow. Foreign credits and aid and Turkish workers' foreign currency earnings abroad were the main sources of finance for this period (Bulutay, 1981:506). Still, until 1967 revenues from agriculture were almost twice industrial revenues at current prices. By 1980, industrial revenues caught up with agricultural revenues. The share of agriculture in GNP decreased from 40% in 1950 to 22% in 1980 and the share of industry increased from 11% in 1950 to 20% in 1980 (Table 4.1). During the early 1970s when the world economy was characterised by stagnation and then recession as influenced by the fuel shock, Turkey managed to achieve positive rates of growth. Thus, the economy grew at 4.75% per year on average between 1970 and 1980. This satisfactory production outcome mainly is attributed to the existing strong growth of consumer demand in Turkey, which formed the grounds for private investment (OECD, 1976). By the mid 70s, sectors with high growth rate were medium-low technology sectors such as chemical fertilizers, paper, copper, coal and iron and steel; whereas low-technology sectors like textiles, food, glass, cement and petroleum products grew moderately (OECD, 1976). At that time the state held almost half of the industrial production and acted as the single actor in basic materials industries like iron and steel, copper, aluminium, etc. During the last years of this period, internal political instability (followed by a coup in 1980) had been damaging for the overall economic growth.

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[33] "Two giant holding companies, Etibank (1933) which concerned itself with manufacturing activities and Sumerbank (1935) which specialized in public operation in mining and electric power, were established" (Singer, 1977:2-3). Both of them are currently privatised. "Further on, in 1937 the state had organized the establishment of the first integrated iron and steel works (Karabuk Demir Celik) and assigned the task of overseeing its construction to British engineers" (Singer, 1977:31).

Table 4.1 GNP growth and sectoral structure of Turkish economy for selected years

Year	Share of Agriculture in GNP (%)	Share of Industry in GNP (%)	GNP (billion USD)	Average GNP growth rate per year (in purchaser's value and in 1987 constant prices) (%)	Periods
1950	40.5	10.8	6.46	-	
1970	25.5	18.0	19.03	3.38	1950-69
1980	22.0	20.0	68.39	4.75	1970-79
1990	17.3	25.3	150.76	4.03	1980-89
1995	15.7	26.3	171.90	3.20	1990-94
2000	13.4	28.3	200.00	4.38	1995-99
2005	11.5	29.4	360.88	4.68	2000-05

Source: Own calculations from data in TURKSTAT (1973, 1997a) and www.tuik.gov.tr

4.2.1.2 Imports and Exports

Before1980, Turkey followed development policies based solely on import-substitution that underpinned her industrialisation process. In application of these kinds of policies, the industrial production did not explicitly aim at exporting abroad and what was produced in the country would mainly be used internally. Yet at that time, Turkish exports performed better in agricultural goods than (low technology) industrial goods (OECD, 1976).

The industrial production needed capital goods and inputs to be imported from abroad. "Demand for imported inputs expanded more rapidly as import substitution required increasingly capital-intensive investments" (Ekinci, 1990:74), especially for the establishment of new factories. By 1974, the proportion of imports covered by exports fell on average to 60%, leaving Turkey with an ongoing balance of payments problem, which is still relevant today.[34] According to Ceyhun (1992:16-7), "import-substitution industrialisation never solved the imports-foreign exchange dilemma, and Turkey's trade balance worsened from 1950s to 1970s", from 1.6% of GNP to 6.4% of GNP. By 1980, the percentage of imports in GNP (11.5%) was almost three times that of exports in GNP (4.25%) (Table 4.2).

[34] From 1923 to 1950 the proportion of imports covered by exports had been 108.2% on average. From 1950 to 1979 this rate was 77% (own calculations from TURKSTAT, 2005).

Table 4.2 Foreign trade of Turkey for selected years

Year	Exports (billion USD)	Imports (billion USD)	Proportion of Imports covered by Exports (%)	GNP (billion USD)	% of exports in GNP	% of imports in GNP
1950	0.26	0.28	92.2	6.46	4.0	4.3
1970	0.59	0.95	62.1	19.03	3.1	5.0
1980	2.91	7.91	36.8	68.39	4.25	11.5
1990	12.96	22.30	58.1	150.76	8.6	14.8
1995	22.00	35.20	62.5	171.90	12.7	20.5
2000	27.77	54.50	51.0	200.00	13.9	27.3
2005	73.48	116.77	62.9	360.88	20.4	32.4

Source: Data and own calculations from SPO (May 1992, August 2006), Ceyhun (1992:16), TURKSTAT (1997a) and www.tuik.gov.tr.

4.2.1.3 Financing Deficits

Foreign exchange shortages caused by the trade deficit accelerated the need for external loans, which eventually resulted in the IMF-imposed stabilization programme in 1958 (Ceyhun, 1992:10). Turkey also started with internal borrowing from the 1980s. In 1980, Turkey's external debts amounted to 27.8% and her internal debts to 20.7% of GNP. In the following years, covering trade and budget deficits by borrowing became habitual in successive governments' policies. As Celasun and Rodrik (1989:194) point out, this mainly was a result of Turkey's "foreign exchange stringency at three junctures: in 1957-58, 1969-70 and 1978-80. Each episode involved IMF-supported programmes involving stabilization with devaluation."

Table 4.3 Outstanding internal and external debts of Turkey for selected years

Year	Internal debts (billion USD)	External debts (billion USD)	GNP (billion USD)	% of internal debts in GNP	% of external debts in GNP
1970		1.96	19.03		10.3
1980	14.16*	19.04	68.39	20.7	27.8
1990	19.54	49.15	150.76	13.0	32.6
1995	29.70	122.05	171.9	17.3	71.0
2000	58.74	118.50	200.00	29.4	59.3
2005	174.84	170.62	360.88	48.4	47.3

Source: Data and own calculations from SPO (May 1992, August 2006), Ceyhun (1992:16).
* For year 1983.

4.2.2 The Post-1980 Period Until 1997

In 24 January 1980, some ‘structural changes’ were made in the Turkish economy under IMF stand-by agreements to overcome the problems that import-substitution industrialisation caused. These changes were mainly characterised by a shift into export-oriented development and industrial policies, trade liberalisation, flexible exchange rates and deregulation in the finance sector. However, the 1980 onwards period was also characterised by financial crises (mainly created by the high external debt burden and outflow of short-term foreign capital) and recurring macroeconomic instabilities, on either the small or large scale. As stated in the OECD Economic Survey of Turkey (1997:2), “Unstable political conditions, extreme inflation and punitive interest rates are usually synonymous with crises and recession. But the Turkish economy has so far proved the exception to this rule.”

4.2.2.1 Industry and Growth

As a major policy change, export-oriented development policies aimed at industrialisation by targeting foreign markets and were supported by flexible exchange rates. As seen in Table 4.1, during the period of 1980 to 1995 the economy grew around 4% per year in constant prices on average, the share of agriculture in GNP decreased from 22% to 15.7% and share of industry increased from 20% to 26.3%. Production of industrial output steadily increased during this period, notably in cement, cotton and woollen fabrics, paper, coal, buses, tractors and chemical fertilizer (OECD, 1982, 1997). The state enterprises in certain sectors (basic metals, chemical fertilizers, communications) still held their monopolies. Yet, starting from 1981, public investment in the manufacturing sector particularly fell by 10% (OECD, 1982) (see Table 4.4 for certain years). The rationale behind the falling public investment had been to minimize unproductive and costly state enterprises and the ones already existing were to be privatised first gradually after 1990s and then aggressively after 2001, paving the way for private initiatives.

Table 4.4 Gross Fixed Investments by selected sectors (% in total public and total private GFI in current prices)

	1980		1990		1995		2000		2004	
	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private
Manufacturing	26.3	30	4.5	26.2	5.6	27.3	2.8	26.7	2.6	42.2
Energy	21.3	0.4	21.7	0.8	13.3	0.7	15	2.9	13.3	1.7
Transport	20.8	9.7	34	10.7	35.1	14.8	35.7	26.2	33.5	18.8
Tourism	0.5	0.6	1.2	5	2.4	2.5	0.5	5.6	0.7	7.6
Housing	2.4	44.7	4	46.5	1.5	43.6	0.8	23.7	1	13.2
Total GFI (billion USD)	5.2	7.8	9.4	21.3	7	32	14	31.6	12.9	43.4
%GFI in GNP	8.7	13.1	7	15.7	4.1	18.6	6.9	15.6	4.2	14.2

Source: Data and own calculations from SPO (May 1992, August 2002, August 2006).

Thus, from 1990 onwards, the governments committed themselves to the privatisation of state enterprises, especially in manufacturing and energy fields, and left most of the economic activities to the private sector by not investing in most of the fields other than energy and transport (see figures in Table 4.4). The gross fixed investments of the public sector in manufacturing industry shrank sharply to 5.6% in 1995 from 26.3% in 1980, leaving the ground almost solely for the private sector. However, on the whole (public + private), investments in manufacturing industry decreased as a result of structural policy changes such as privatisation. Contrary to expectations, in the 1990s privatisation did not give an impetus to the private sector's investments especially in the field of manufacturing. Because of the existing debt policy and high interest rates, possible entrepreneurs opted for lending money to the state instead of taking risks by choosing industrial production. "Business may have earned up to a half of its profits by holding government paper" (OECD, 1997:3). This is reflected in the figures for GFI of the private sector in manufacturing industry falling from 30% of GNP in 1980 to 27.3% in 1995. This is also supported by the decrease in capital goods imports from 20% in 1980 to 16.3% in 1995 as percentages of total imports (Table 4.5). In the case of a technologically improving manufacturing industry, capital goods imports should increase, since these consist of imports of machinery in a developing country technologically dependent on industrialised countries.

Table 4.5 Imports by classification of broad economic categories BEC (% in total imports)

Year	Total Imports (billion USD)	Consumption Goods (%)	Capital Goods (%)	Intermediate Goods (including crude oil) (%)
1980	7.9	2.2	19.9	77.9
1990	22.3	9.4	18.3	72.2
1995	35.2	12.4	16.3	71.3
2005	116.7	12.5	17.4	70.1

Source: Ekinci (1990:104), TURKSTAT (1997a), SPO (August 2006).

Although there were considerable achievements in decreasing the role of agriculture in the Turkish economy in this period, this created further problems. Since as much as 50% of the labour force was engaged in the agricultural sector, industrialisation policies applied without strong infrastructure and planning caused villagers to move into the cities. The surplus of unskilled human force could not be absorbed by other sectors, causing sociological problems and overpopulation in the cities. The 6.3% increase in the share of industry in GNP during the 15 years from 1980 to 1995) (see Table 4.1) had been below expectations for concrete achievements regarding the labour force re-allocation. It was also not an achievement regarding the technological improvements, productivity and competitiveness in the industrial sector.

Despite all the difficulties, there had been some progress in terms of long-term achievements on the whole regarding industrial specialisation. For instance, Dalum (1992: 203-4) in a comparative study of RCA indices for five sectors in 21 countries based on OECD's Trade by Commodities Database for the 1961-1987 period, reported that Turkey's specialisation patterns did show *some* change from specialisation in resource-based products at the beginning of the 1960s to specialisation in traditional industries by the early 1980s.

4.2.2.2 Imports and Exports

During the 1980-1995 period, the proportion of imports covered by exports had been 52.5% on average (see footnote 2 for previous periods' proportions). Strikingly, this rate is lower than the rate when import-substitution policies were being applied. In other words, export-led industrialisation was not successful in yielding any significant progress in terms of substantial increases in exports to cover most of the imports, compared to the 1950-1980 period, despite the fact that both exports and imports increased in current and in constant prices. However, it can be argued that the shift to liberal policies, from 24 January 1980 onwards, helped Turkey to get out of the bottleneck that she was stuck in as regards trade balances. As seen in Table 4.2, the proportion of imports covered by exports was only 36.8% in 1980, having fallen further from 44% in 1979. The immediate effect of the January 1980 policies (trade liberalisation and devaluation of Turkish currency) lifted this measure up to 52% in 1981, creating an export boom, which included a broad range of consumer and investment goods (OECD, 1982). Turkey managed to keep this rate steady between 50%-62% in the following years by regularly devaluing its currency to promote exporting sectors.

4.2.2.3 Financing Deficits

The habit of covering budget and trade deficits by internal and external borrowing went on during this period. High PSBRs (public sector borrowing requirements) were the underlying reason for high inflation rates (OECD, 1997). The debt burden heavily increased, reaching 88% of GNP in 1995 (see Table 4.3 for elaborations). Towards the end of this period, although public expenditures decreased strikingly in almost all the fields of the economy, the vast majority of the money borrowed was used in paying back some of the loans and their interest. Along with this, deregulation in the finance sector took place to attract foreign capital into domestic markets. Such regulations would also ease borrowing from abroad.

4.2.3 The Period From 1997 Until 2005

The third period (1997-2005) shows similarities with the second period (1980-1997) in terms of the economic policies applied until 2001. However, starting with the single party government in 2001, the pace of economic policy applications changed. The structural reforms, which were highlighted in 1997, were put into action one after another. These included deeper deregulation especially in the finance sector and widespread privatisation of state-owned enterprises in communication and energy fields and especially banks, leaving the exchange rates in a floating regime to protect the wider economy from the more catastrophic consequences of a crisis, along with Central Bank independence.

4.2.3.1 Industry and Growth

With a population approaching to 80 million in 2005, Turkey is a country with extensive internal demand. This strong internal demand has positive influences on ongoing growth in the economy. The Turkish economy was stated as being among the fastest growing economies in the OECD (OECD, 2004). The economy grew around 4.68% per year in constant prices on average (Table 4.1) between 2000 and 2005. Although it shrank by 7.5% in 2001 after hitting its most severe crisis of its recent history, GDP recovered to grow by 8% and 6% respectively in 2002 and 2003 (OECD, 2004) and by 9% and 7.5% respectively in 2004 and 2005 (OECD, 2006). According to the OECD Survey of Turkey (2004:11) growth “is driven by strong productivity gains and by robust private consumption, investment and exports”. It was mainly driven by the growth of industrial output of more than a third over the 2002-05 period (OECD, 2006).

The share of agriculture in GNP decreased further to 11.5% and the share of industry increased to 29.4% by 3% in the 10 years to 2005 (Table 4.1). Differently from previous years, private gross fixed investments in the manufacturing sector increased to 42% of GNP in 2004 (Table 4.4). This was a substantial increase compared to 26.7% in 2000. Other than the reasons stated above by the OECD, this also relates to the success of the ongoing IMF programme and the single party rule on the political side, bringing some stability.

4.2.3.2 Imports and Exports

From 1997 to 2005 “exports continued to grow, but so did imports, as a significant proportion of the inputs in the export-oriented sectors is procured from abroad” (OECD, 2004: 53). The import to export coverage proportion increased slightly to 57% on average. The general openness of the Turkish economy was striking, in that trade accounted for more than 50% of GNP by 2005 (Table 4.2).

Turkey’s export structure has significantly changed from exportation of mainly agricultural products to industrial products within the last 25 years. According to the World Bank (2005: 299) figures, Turkey’s manufactured exports in 2003 amounted to 84% of its total merchandise exports, depicting a much-improved state from 27% in

1980 and 74% in 1996 (World Bank, 1998:190). This figure reached 94% in 2006 (SPO, 2007).

However, most of the manufacturing exports have been in the category of low-tech products. As listed in UNIDO (2002:165) in 1998 (see Table 4.6), the share of low-tech[35] and resource-based manufactured exports of Turkey in its total exports was 61.7%, of which 49.2% was low-tech exports and 12.4% was resource-based. 23.5% of manufactured exports were, on the other hand, classified as medium and high tech, of which only 5.3% was high-tech exports and 18.1% medium-tech exports. By the beginning of the third period of this analysis, Turkey ranked 36th among countries of the world, as assessed by its 23.5% of medium- and high-tech exports share in its total exportation in1998.

Table 4.6 Technological structure of Turkish manufactured exports, 1998 and 2006 (%)

Years	**Proportion of manufactured exports in total exports**	**Complex exports**		**Simple exports**	
		High tech	**Medium tech**	**Low tech**	**Resource based**
1985	72.8%	1.2	17.1	38.6	15.9
1998	85.2%	5.3	18.1	49.2	12.4
2006	94.1%	6.3	29.1	45.5	13.1

Source: UNIDO (2002:165) and SPO (2007).

The technological structure of Turkish exports had changed in favour of complex exports by 2006. Medium-technology exports increased significantly (29%), though high-technology exports increased only slightly (6.3%) (Table 4.6).

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[35] UNIDO (2002) provides a categorization of manufactured products by technology intensity (but see von Tunzelmann and Acha, 2005, for reservations about this terminology). According to this classification of UNIDO (2002:30):
(i) Resource-based manufactures are processed foods and tobacco, simple wood products, refined petroleum products, dyes, leather, etc., which do not require scale or skills and are mostly labour-intensive;
(ii) Low-tech manufactures are textiles, garments, footwear, leather products, toys, simple metal and plastic products, furniture and glassware, which require low R&D expenditures and skills;
(iii) Medium-tech manufactures are heavy industry products such as automobiles, industrial chemicals, machinery and standard electrical and electronic products, which require moderate levels of R&D expenditures, but advanced engineering skills and large scales of production; and
(iv) High-tech manufactures are complex electrical and electronic products, aerospace, precision instruments, fine chemicals and pharmaceuticals, which require large R&D investment and complex skills.

Starting from the early 2000s, China's emerging clothing and textile sectors, especially, put pressure on those of Turkey. According to OECD (2006), despite export performance of total goods and services showing significant increase since 2000, because almost a third of Turkey's manufacturing exports were in textiles, clothing and leather sectors, competition from China, India and other Asian countries caused an apparent decline in these sectors in terms of export performance. Yet different sectors were differently affected by the recent trends in the economy. The results of a recent analysis on the "profit margins of seventeen manufacturing sectors between 1998 and 2005 at aggregate and sectoral levels by drawing on the standard methodology of calculation of unit labor costs" (OECD, 2006:117) are interesting. The Turkish manufacturing sector clusters in three groups and shows the following characteristics (OECD, 2006:119-20):

(i) electronics, industrial machinery, steel and car manufacturing are highly competitive sectors and do consistently well;

(ii) plastics, electrical equipment, metal products and furniture manufacturing are intermediary sectors with mixed performances in competitiveness;

(iii) textiles, clothing and leather industries are declining sectors with a severe deterioration in competitiveness.

The figures in Table 4.6 and the results of recent OECD research suggest that within the last eight years (from 1998 to 2006) Turkish exports have shifted significantly towards medium-tech and slightly towards high-tech manufactured exports, and away from low-tech manufactured exports and agricultural exports.

4.2.3.3 Financing Deficits

Despite privatisation and export efforts, the economy heavily relied on internal and external debt; so the debt burden increased to 96% of GNP by 2005. The majority of external debt was (and still is) in the form of short-term capital inflow. In a politically volatile economy, this kind of foreign capital inflow can easily be transformed into an outflow, causing serious damage to the economy. Turkey experienced such a financial crisis in February 2001, which "was brought by the failure of the disinflation program launched in December 1999 whose core instrument was a crawling peg between the Turkish Lira (TL) and a basket of the Euro and Dollar. The consequences of the floating of the TL (February 2001) were an acceleration of inflation (the CPI index increased by 68% after rising 45% in 2000), a fall of the exchange rate, a collapse of domestic demand and a banking crisis"(Chaponniere and Boillot, 2002).

By 2004, imports started growing faster than exports as a result of overvaluation of the Turkish currency. It would have been a serious problem to finance the deficit had privatisation efforts not yielded considerable income, particularly during the last few years.

By 2007 interest rates were lowered to 15% from 80-90% during the 1990s. Lower rates of real interest created favourable conditions for investments in industry. Also, it was hard for an economy with politically and economically volatile conditions to attract foreign direct investment (FDI). Turkey lived with the disadvantages of its unfavourable conditions for FDI until almost 2003. Only after political stability was to some extent confirmed and followed by economic stability during the last few years did foreign investors become more interested in investing in primarily Turkish automotive and communication industries in the form of joint ventures. This is also confirmed by the increasing shares of medium-tech and high-tech industries in Turkish exports.

4.2.4 Summary

Turkey's economic history is characterised by three distinct periods, during which the economy shifted from the dominance of the agricultural sector to the dominance of industry and services. From 1923 until 1980, import-substitution policies underpinned the industrialisation process, while agriculture accounted for more than half of the output in the economy. Since 1980 liberalisation in macroeconomic policies and export-orientation policies in the industry took over, which gave some impetus to the recovery of industrial sectors. After numerous cases of political and economic instability and financial crises, finally, since the beginning of 2000s, Turkey has come to enjoy economic stability with decreasing inflation and interest rates, increasing growth in manufacturing industries, which is supported by one-party political stability. Despite that, the economy seems very fragile, because it still is one of the economies with the highest internal and external debt burdens in the world.

One strategy to overcome the persistent problems in general in the economy might be to aim at structural change in the industrial sector and invest heavily in medium- and high-technology industries as opposed to declining low-technology industries,[36] and increase the production of knowledge-intensive products as an important feature of economic change in countries like Turkey. In fact, from 1961 to the mid 2000s, Turkey managed to shift its industrial specialisation patterns first from resource-based to traditional products and then to medium-technology products.

4.3 High-Technology Industries in Turkey: the Case of the Materials Industry

This section presents some figures on high-technology industries in Turkey. Definitions, types, taxonomies and application fields of materials (both traditional and advanced) have been widely and technically discussed in Appendix A of this thesis. These materials include: composite materials such as metals, polymers and ceramics reinforced with variety of fibres; structural and functional ceramics; structural polymers; rapidly solidified, microcrystalline and glassy metals; and innovations in surface engineering, in particular certain coatings designed to procure certain property advantages (Hondros, 1988).

In manufacturing industry, production of advanced materials has spread into different sectors dealing with powder metal parts, fibreglass, technical ceramics, optical fibres, composites such as ceramic-metal composites, fibreglass reinforced composites and carbon pre-impregnated composites, etc. OECD classifies manufacturing industries according to their R&D intensity (Table 4.7). High technology industries stand out with their high R&D intensities. In this classification, production of advanced materials fall into the categories of: aircraft and spacecraft; medical, precision and optical instruments; and radio, television and communications equipment in high technology industries; also other non-metallic products and fabricated metal products in medium-low technology industries.

[36] Seymen and Simsek (2006), in their analysis of the Revealed Comparative Advantages of Turkey and China, show that besides low technology exports, even Turkish medium technology exports are under growing competitive threat from China. Therefore, Turkey needs to develop further strategies to compete with countries like China, India, etc., in the very near future in order to keep its growing deficits at a sustainable level.

Table 4.7 OECD classification of manufacturing industries

Category	Name of the industry	ISIC rev. 3 code	R&D intensity 1997
High technology industries	Aircraft and spacecraft	353	12.7
	Pharmaceuticals	2423	11.3
	Office, accounting and computing machinery	30	10.5
	Radio, television and communications equipment	32	8.2
	Medical, precision and optical instruments	33	7.9
Medium-high technology industries	Electrical machinery and apparatus, nec	31	3.8
	Motor vehicles, trailers and semi-trailers	34	3.5
	Chemicals excluding pharmaceuticals	24 excl.2423	2.6
	Railroad and transport equipment, nec	352+359	2.8
	Machinery and equipment, nec	29	1.9
Medium-low technology industries	Coke, refined petroleum products and nuclear fuel	23	0.8
	Rubber and plastic products	25	0.9
	Other non-metallic products	26	0.9
	Building and repairing of ships and boats	351	0.7
	Basic metals	27	0.7
	Fabricated metal products, exc. mach. and equip.	28	0.6
Low technology industries	Manufacturing, nec and recycling	36-37	0.4
	Wood, pulp, paper products, print and publishing	20-22	0.3
	Food products, beverages and tobacco	15-16	0.4
	Textiles, textile products, leather and footwear	17-19	0.3
	Total manufacturing	**15-37**	**0.3**

Source: (OECD, 2001).

A list of materials produced by Turkish manufacturing industry is provided in Table 4.8. Appendix A discusses technical details of these products. It also provides in-depth information about the materials and processes used in production of these products, along with some other higher technology implications in various parts of the world.

As seen in Table 4.8, materials production in Turkey is classified into two:

(1) Products identified by their structural[37] properties and by the use of medium technology processes in production; and by their application in medium technology sectors, such as ferrous and non-ferrous metal parts for the automotive sector, iron and steel, standard glass and ceramic sectors, standard electronics, etc.

(2) High technology products identified by their functional[38] properties and by the use of higher technology processes and use of R&D; and by their application in

[37] Structural properties of a material refer to mechanical properties such as high strength, high-temperature strength, wear resistance and lightweight.

[38] Functional properties of an advanced material refer to the physical, chemical and biological functions possessed by the material. These are high thermal conductivity or insulation, high electrical conductivity or resistance, high chemical stability, piezoelectricity, corrosion resistance, biocompatibility, etc.

high technology sectors such as telecommunications, complicated electronics, defence and aircraft, etc.

Table 4.8 List and categorization of products produced by sample firms in this study

<table>
<tr><th>Degree of novelty of product</th><th>Material group the product belongs to</th><th>End Product</th></tr>
<tr><td rowspan="11">Structural materials produced by mature technology firms (Medium-low technology industries)</td><td rowspan="6">Iron and copper based powder metal parts for automotive industry</td><td>Low density parts (high porosity, 25-60% porous): Metallic filters, self-lubricating bearings</td></tr>
<tr><td>Medium density parts (15-20% porosity): Automotive shock absorber pistons, oil pump rotors and gears</td></tr>
<tr><td>High density parts (porosity less than 10%, high strength is vital): Gears, seal parts</td></tr>
<tr><td>Electrical contacts (CuW, AgW, WC): Low and high voltage circuits, electrical circuit breakers, electrodes</td></tr>
<tr><td>Carbon brushes (graphite, Cu): Automotive starter motors (for a wide range of auto types), alternators</td></tr>
<tr><td>Friction discs</td></tr>
<tr><td>Hard metals-metal composites for metal manuf. ind.</td><td>Indexable inserts, clamping tools for milling and turning, dies for presses, extrusion and cutting tools</td></tr>
<tr><td>Glass</td><td>Fibre glass</td></tr>
<tr><td>Metal</td><td>Metal coatings by electrolysis</td></tr>
<tr><td>Ceramics</td><td>Refractories</td></tr>
<tr><td>Glass</td><td>Optical fibre</td></tr>
<tr><td rowspan="12">Functional materials produced science-based technology firms (High technology industries)</td><td>Plastics</td><td>Fibre reinforced composites</td></tr>
<tr><td rowspan="11">Technical ceramics</td><td>Electro porcelain parts: Low and medium tension insulators</td></tr>
<tr><td>Steatite parts: Fuse insulators, thermostat and switch bases, connector bushes, terminals, terminal beads</td></tr>
<tr><td>Cordierite parts: High thermal shock resistive insulating parts, inserts of electrical heaters, honeycomb catalytic converters, honeycomb strainers for metal casting.</td></tr>
<tr><td>Aluminium oxide parts: Seal rings, spark plug insulators for domestic appliance, thermostat parts, thermocouple tubes, grinding discs, ballistic protection plates, grinding balls</td></tr>
<tr><td>SiC composite products: Geometrical shape grinding and polishing chips for metal surface treatment</td></tr>
<tr><td>Mullite-cordierite parts: Ceramic infrared gas heater plates.</td></tr>
<tr><td>Ceramic ferrites</td></tr>
<tr><td>Oxygen sensor</td></tr>
<tr><td>Piezoelectrics</td></tr>
<tr><td>Thin film ceramic coatings on metal and glass surfaces</td></tr>
</table>

Source: Compiled from interviews in the firms and TURKSTAT (2005a).

The technical grounds for such a classification are presented in Appendix A. As explained further in Chapter 5, this classification will also prepare the basis for studying and comparing two different segments, namely mature technology firms and science-based technology firms, in the Turkish materials industry.

4.3.1 Structural Materials Produced in the Mature Technology Segment of the Industry

Production of structural materials is embedded in different sectors of the industry, such as automotive parts, metal manufacturing, glass and ceramic refractories.[39]

This study encompasses firms in the automotive parts and metal manufacturing industries that produce small and tiny metal parts of iron or copper based metal powders generated by pressing methods (powder metallurgy techniques) and used as bearings, shock absorbers, pistons, seals, etc. Some other companies in the metal manufacturing industry also produce high-strength dies and presses from hard metals and metal alloys. These products possess high mechanical strength. There is around 28-30 of such firms in Turkey operating especially in this specific field.

Among the structural materials fibreglass is another that is used as an input in composite material production to provide greater mechanical strength. Fibreglass is a product of the glass industry. There is only one firm in Turkey producing fibreglass. This study does not deal with other types of glass products such as flat glass, industrial containers and household goods. Total production of the glass industry amounted to 1.9 million tons per year in 2005, with fibreglass production only 43,000 tons per year (SPO, 2006a: 106).

Metal coating by chemical electrolysis methods is another way of strengthening metals as well as improving their anti-corrosive properties. Compared with recent metal coating methods, electrolysis is a mature technique. So are the products of electrolysis.

The traditional ceramics sector is identified with the production of building materials and sanitary materials. Turkey ranks the fifth in the world, after China, Italy, Spain and

[39] Production techniques are described in detail in Appendix A.

Brazil in traditional ceramics production, but this study will not deal with these products. However, refractories with high thermal strength and with properties providing durability against physical and chemical effects of fluids and gaseous phase substances will be discussed as within the scope of this study. Refractories are ceramics based materials made of quartz, magnesite, chromite, graphite, etc. They are used in lining the inner walls of heavy industry furnaces, especially in the steel industry. There are 19 firms operating in the field of refractory production. In 2002, total production of these firms amounted to 282,000 tons per year.

4.3.2 Functional Materials Produced in the Science-based Technology Segment of the Industry

Production of functional materials is also embedded in different sectors of the industry. Production of optical fibres for telecommunications, fibre reinforced composites for the defence and aircraft industries and technical ceramics for the electronics and manufacturing industries will be examined in this category.[40]

There is only one optical fibre producing company in Turkey. In 2001, the firm produced 450,000 fibre*km of optical fibre and 24,000 cable*km of fibre-optic cable per year, and 4 fibre-optic preforms per day.

The firms producing fibre-reinforced composites mainly work for the defence industry. There are around 6 firms in this category working in close co-operation with the military. The military's own firms, which produce armaments, are not counted among these firms.

In the technical ceramics category, there are products such as insulators, isolators, piezoelectric ferrites used for electrical and electronic purposes; catalytic converters, strainers, oxygen sensors used in casting and the steel industry; thin film ceramic coatings applied on metal, plastic and glass surfaces to provide anti-wear, frictionless surfaces, anti-corrosion, high thermal resistance materials used in the textile, automotive, defence, aircraft and cutting tools industries and bio-medical applications such as hip and knee prostheses, bone joints and medical knives, etc. There are

[40] Production techniques are described in detail in Appendix A.

altogether 13 firms operating in the field of technical ceramics and 8 firms operating in the field of electricals and electronics. The firms operating in these fields change in size depending on the industry they are producing for. Firms producing for the defence industry are medium-sized old firms, whereas thin film ceramic coating firms are small, young firms with engineer-manager entrepreneurs. Even though their activities currently remain limited, using the technical workforce and the knowledge embodied in this workforce remains promising for the future. These firms search for, apply for and receive R&D grants proposed by certain institutes of the innovation system in Turkey such as TIDEB and TTGV funds.

Since technical ceramics production is widely spread across different industrial sectors and sub-sectors, it is not possible to obtain clear-cut figures of production and consumption. However, in the next part, import and export values are presented.

4.3.3 Importation and Exportation of Structural and Functional Materials in Turkey

The Turkish Statistical Institute does not maintain production and consumption statistics of the above-discussed traditional and advanced materials. Even if it were possible to have these statistics, they would not be reliable, since the companies usually do not reveal the real figures for production because of tax matters in Turkey. Thus, to give an idea about the condition of the materials industry, import and export values of some of the materials covered in this study are shown in Table 4.9. The Turkish Statistics Institute gathers these statistics (GTIP – Customs Tariff and Statistics Position) according to 'Customs Entry-Exit Declarations' by Customs Offices throughout Turkey. Then, they are organized on the basis of the 'Harmonized System Nomenclature' of the EU and according to 'statistical positions' arranged in the 8-digit code of the 'Customs Entry Instructions'.

From Table 4.9 the following outcomes could be drawn regarding the materials sector in Turkey:

- It is more import-oriented than export-oriented. The rate of exports of functional materials is higher than that of structural materials.

- There was a considerable increase in 2005 in the export rates of especially structural materials. This was due to favourable conditions in the automotive industry, which is the main buyer for iron and copper based powder metal parts.
- Demand for functional materials is mostly covered by imports. Domestic production meets some of the internal demand with negligible rates of export.
- More than half of the exports of functional materials are of fibre optics. Technical ceramics account for less than half. And among the technical ceramics, exported items fall into medium technology category products such as fuse insulators and aluminium oxide parts rather than high technology ones.

Table 4.9 Import and export values of structural and functional materials in Turkey for selected years, value in million USD

Material group		End Product	1997		2000		2005	
			imports	exports	imports	exports	imports	exports
Structural materials	Metal	Iron and copper based powder metal parts for automotive ind.	344.4	77.4	257.9	102.6	587.7	367.3
		Hard metals-metal composites for metal manufacturing ind.	36.2	2.3	43.1	2.2	43.9	39.3
		electrolysis	0.5	0.1	3.6	0.05	2.9	0.2
	Glass	fibreglass	21.9	34.5	25.5	37.2	66.0	81.4
	Ceramics	refractories	24.6	11.2	13.8	8.7	38.2	32.8
	Structural materials total		427.7	125.4	343.9	150.7	738.8	521.0
Functional materials	Glass	fibreoptics	7.8	12.7	4.1	23.6	4.2	23.0
	Technical ceramics	Electro porcelain parts: Low & medium tension insulators	3.8	0.3	3.0	0.2	3.1	1.3
		Steatite parts: Fuse insulators	6.3	2.3	7.5	1.3	10.8	4.3
		Aluminium oxide parts: Seal rings, thermostat parts, thermocouple tubes.	37.3	2.3	29.3	1.4	57.7	11.9
		Ceramic electric condensors	8.6	0.1	17.4	0.1	11.0	0.1
		Cordierite and mullite-cordierite parts: honeycomb strainers for metal casting.	9.8	0.03	15.2	0.1	23.1	0.1
		Ceramic ferrites	8.6	0.1	6.4	0.3	12.9	0.2
		Piezoelectrics	6.9	0.01	1.9	0.1	3.7	0.0
		Thin film ceramic coatings on metal and glass surfaces (only for titanium oxide)	8.5	0.1	6.7	0.02	7.4	0.1
		Ceramic-metal composites	0.9	0.02	0.1	0.00		
		Technical ceramics total	81.2	5.1	80.6	3.5	122.4	18.0
	Functional materials total		89.0	17.8	84.8	27.2	126.6	41.0

Source: TURKSTAT (1997b, 2000, 2005a).

4.3.4 Summary

Previously, it was stated that a strategy to overcome the persistent structural problems in the economies like Turkey depends on a successful shift from the production of resource-based products to traditional products and then to the production of medium and high technology products in the industry. Section 4.3 of this chapter discussed the condition of the materials industry in Turkey in this perspective.

Materials production in Turkey is classified into two as (i) products identified by their structural properties and by the use of medium technology processes in production; and by their application mainly in medium technology sectors, and (ii) high technology products identified by their functional properties and by the use of higher technology processes and use of R&D; and by their application in high technology sectors. The import and export statistics of materials in Turkey reveals that there have been some significant changes in the industry during the last few years of this research, for instance increase in the export rates of structural materials due to favourable conditions in the user automotive sector and also in the production of fibre optics and technical ceramics. The statistics show that there is potential in the Turkish materials industry for increased production and export rates. A successful outcome can be achieved via the careful introduction and application of tools of an innovation system, particularly for the specific materials industry.

The way the industrial specialisation patterns change and progress shapes the innovation system in a particular country. Dalum (1992:204) states that "national innovation systems run through life cycles". That is, many developed countries which do not experience changes in their industrial specialisation patterns may be characterised as mature innovation systems, while changing specialisation patterns lead to emerging and evolving innovation systems in a country.

Turkey showed a steady change in its industrial specialisation patterns from resource-based to traditional products (from the beginning of the 1960s to the end of the 1980s) and then to medium technology products (from the 1980s to mid 2000s). Section 4.4 below investigates the initial and the existing conditions for an emerging and evolving innovation system in Turkey largely at the policy level as determined by the successive governments. The institutional framework for the innovation system in Turkey is provided here only to precede the empirical research on the emerging 'knowledge networks' leg of the innovation system literature as analysed in Chapters 6 and 7. It must be noted that the boundaries of this research are determined by the 'knowledge networks' in the innovation system. Moreover, I will deal only with a few highly selected aspects of the knowledge network – in particular just three, namely the origins of links in the system, the actors in the system, and the density of links in the system.

4.4 The Innovation System in Turkey

This section is structured in two parts. Each is shaped according to the three periods analysed in this study. First, the institutional set-up of the system's main actors and their roles will be introduced along with the science and technology policy documents released by the policy actors. This will be followed by introduction of the knowledge network actors and whether system interactions exist or not will be explored with regard to underlying problems known or not known.

Components of the innovation system in Turkey will be presented in two sections as previously discussed in Chapter 2:
(i) The institutional framework including legislations and actors, which underline the innovation policy framework and is expected to serve as the background of an emerging innovation system policy (section 4.4.1);
(ii) The knowledge networks and interactions, the actual components of an innovation system (section 4.4.2).

The institutional framework is understood here as "intentionally designed public policies, i.e. regulations, laws, norms, policy guidelines and programmes, which have an implicit or explicit objective to influence S&T development; whereas knowledge networks are about the *acquisition*, *combination*, *generation*, *exchange* and *transfer* of complementary and heterogeneous knowledge and capabilities contributing to learning and innovation" (Dantas, 2006:54, 43).

4.4.1 The Institutional Framework

This section will deal with the public policy component of the innovation system and its actors in Turkey.

4.4.1.1 The Pre-1980 Period

The pre-1980 period was characterised by industrialisation policy implications but not science and technology policies. However, one can argue that the background of the innovation policy dates back to 1963 in Turkey when the First Development Plan (1963-1967) was launched. This attempt may be regarded as the very first step towards the formation of the institutional framework for the innovation system exerted by the state itself; simply because shortly after, it was followed by the foundation of the Scientific and Research Council of Turkey (TUBITAK). Since then TUBITAK has been the main coordinative and governmental body responsible for the implementation of science and technology policy in Turkey. It advises decision makers and at meetings with legislative bodies described below, TUBITAK is responsible for policy making in science and technology policies in Turkey.

4.4.1.2 The Post-1980 Period Until 1997

Some initial yet largely incomplete steps had been taken during this period in an attempt to create the national innovation system in Turkey. The main task happened to be the establishment of some governmental bodies that would be influential in the next period. In 1983 the Supreme Council of Science and Technology (BTYK) was established. BTYK would become the main legislative body, above all institutions, to coordinate the policy and decide about what legislation and laws should be accepted and how applied. It is chaired by the prime minister and is composed of the related ministries, high-level representatives of the government bodies, universities and NGOs (http://www.tubitak.gov.tr/btpd/btspd/biltekyo/abtyk.html). Yet, BTYK would have its second meeting only 10 years later in February 1993.

At this meeting in 1993 BTYK produced the first important policy document 'Turkish Science and Technology Policy: 1993-2003'. As stated on TUBITAK's own web page, this document aimed for Turkey to gain technological capabilities especially in the fields of critical technologies of ICT, advanced materials and biotechnology, and set targets for increasing R&D expenditures, number of researchers, etc. However, this document could not achieve all of its ambitious targets other than some arrangements regarding intellectual property rights and patents, such as establishment of the Turkish

Patent Institute and some modest tax incentives for R&D expenditures of private firms. Even TUBITAK accepts that the decisions in the policy document could not be applied with systematic continuity, decisiveness and cooperative participation of all institutions in the system, but rather individual efforts of each institution on its own (www.tubitak.gov.tr/btpd/btyk).

During this period, maybe the most important achievements towards a state-initiated innovation system in Turkey were the establishment of other governmental and non-governmental bodies, which were formed to help with implementation of legislation, create awareness about innovativeness in the industry, support SMEs, provide R&D financial support, host technology development centres and get involved in the formation of techno-parks etc. Their activities gained pace after 1999 in parallel with the increasing activities of decision makers.

The Small and Medium Sized Industry Development Organization (KOSGEB) was founded in 1990 and is affiliated to the Ministry of Industry. It was explicitly established to support SMEs by any means. Especially after 1995, KOSGEB was active in its technology development centres built for high-technology SMEs in close proximity to technical universities. These firms are provided with consultancy and training in the fields of technology and innovation and finance; they are encouraged and put into interaction with the related university departments for joint research projects and experimental facilities.

The Technology Development Foundation of Turkey (TTGV) is a World Bank funded non-profit organization. It was established in 1991. TTGV takes part in the vast majority of the actions undertaken by TUBITAK. Among the industrial firms, TTGV has a good reputation for technological consultancy and the financial support they give to increasing firms' innovative activities.

TUBITAK founded TIDEB (Support and Assessment Unit for Technological Innovation) in 1995. It is charged with the implementation of the university-industry joint research centres programme and activities to increase awareness about innovation. It supports R&D projects of the industry financially. However, among the industrial companies it is mostly identified with its modest financial grant of around 150K USD for R&D projects. Although there are firms that only received TIDEB grants, in most of the cases projects that were supported by large R&D loans from TTGV (up to 1 million USD) were also rewarded with TIDEB funds.

4.4.1.3 The Period from 1997 Until 2005

During this period BTYK released a series of STP documents. All of these documents, basically in their core, aimed at the National Innovation System in Turkey and regarded this as an emergency issue (www.tubitak.gov.tr/btpd/btyk).

Thus, 'as early as' 1998, the National Innovation Project started. TUBITAK guided the project together with TTGV, TURKSTAT and KOSGEB. Experts from the universities contributed to the project. The project objectives were ambitious: to study the development of the national system of innovation in Turkey and compare the Turkish innovation system with those of the developed and newly industrialising countries; analyse the direction of structural change in Turkish manufacturing industries and identify their innovative potential; analyse technological capacity of SMEs in Turkish manufacturing industries and evaluate technology-based SME support policies; evaluate and assess technological and economic effects of the R&D support instruments (R&D grants by TUBITAK-TIDEB and R&D loans by TTGV); and evaluate how the innovation system in Turkey functions, identify major problems, and propose new policies (EC and KOSGEB, 2002:21).

Although considerable resources and time have been invested in the project, eventually launching the R&D financial support programme for the firms by TIDEB and TTGV has been the only solid outcome of this project. This programme proved to be successful in the following years. For instance, the majority of the firms in the sample of this research made use of these R&D supports in their research projects.

The ultimate goal for a national innovation system in Turkey continued, with decisions taken on further large-scale projects. This time, the large task was divided into sub-projects about Turkey's technology transfer directions and technological balance of payments tables; a bibliometric study of the number, field, quality and geographical diversity of Turkish researchers and the brain drain; long-term technology foresight for determining strategic targets; continuous follow-up of the Turkish national innovation system and revising support policies in ways that could be implemented. This project was narrowed down to a bibliometric study of Turkish researchers and was called the "Turkish Research Area" (TARAL) in 2004, where the private and public sectors and non-governmental organisations strategically focus and collaborate for R&D. TARAL became the hope of decision makers to serve as grounds for systemic interactions. Since then, TARAL has been perceived as the backbone of the national innovation system. According to a recent document released by the World Bank (2006:58), TARAL has "a key objective: that of increasing institutional capacity for innovation and supporting public-private cooperation in this area, but more effort is needed to ensure that Turkey has coherent programmes and capacity to utilize these resources effectively."

Turkey set new targets to increase the share of R&D expenditures in GDP to 2% by 2004, but the real figures were far from reaching the target. The percentage of total R&D expenditures in GDP increased from 0.61% in 2003 to 0.67% in 2004, amounting to 2 billion USD. R&D expenditures in higher education amounted to 68% of all R&D expenditures in 2004, whilst the business sector's share was 24% and the government's 8% (TURKSTAT, 2006). These shares were the same in 1997 according to OECD statistics (2001:22). Therefore, innovation policy implementations were not successful in creating a favourable environment for increasing business R&D expenditures, which are currently among the lowest within the OECD countries.

Increasing firms' investments in R&D is one of the key determinants in climbing up the technological ladder in an innovation system. To achieve this, two main goals were targeted: (i) to increase private investment in innovation, and (ii) to increase firm-university collaboration. Tax incentives and research grants are used as tools to achieve the first goal. New legislation has been introduced regarding state support for R&D expenditures of companies. Introduction of tax incentives to SMEs on their R&D expenditures has been formalised and currently applied. However in practice, since SMEs do not have sufficient profits to use the tax benefits, tax incentives remain a weak tool (World Bank, 2006). To complement that TUBITAK-TIDEB and TTGV provided R&D project grants and reimbursable loans for innovative SMEs as mentioned earlier. Lack of venture capital to support the start-up companies for R&D projects is an important handicap. Although the necessities for venture capital firms have been raised and measures have been put forward to increase the number of such firms, in 2005 the number of these venture capital operations was no more than a few. There are only two venture capital companies that have very recently been established in Turkey. There are no foreign venture capital funds domiciled in Turkey, either. Most of the SMEs are family-owned companies; venture capital and private equity direct investment is a relatively new phenomenon in Turkey and faces a number of barriers, many of them cultural. Turkish companies have often resisted outside ownership and control, while participating in fairly extensive extra-legal operations in order to avoid taxes (EC & KOSGEB, 2002: 19-20). Because of the macroeconomic instability and high inflation rates making borrowing costly, access to funding is very limited for SMEs. As a consequence, R&D expenditures on the whole and moreover R&D support given to SMEs is not sufficient to encourage firms to co-operate with the universities.

The second remedy to encourage firms to invest in R&D was aimed to be achieved via establishing technology development zones and techno-parks close to universities. Soon after the law for the foundation of Technology Development Centres was approved (in 2002), 14 centres had been founded in Turkey by 2005. Technology Development Centres (TEKMER) are run by KOSGEB. These are incubators for high-tech start-up firms located near a university to ease university-industry relations. Also, 17 techno-parks throughout the country host high-tech firms, which successfully completed the incubation period and transferred to a techno-park. The vast majority of the companies located in technology development centres and techno-parks are engaged in consultancy, information and communication technologies. ICT firms, especially, have some relations with the nearby universities' computer engineering departments. In addition to these, two university-industry research centres have been founded, one in Adana, in the South-east and one in Eskisehir, in Central Anatolia. The latter is a ceramics research centre.

Despite failures in most aspects, this period has been a successful one for increasing awareness about the 'innovation' concept among the firms and in society in Turkey. For instance, as a consequence of a large number of decisions taken by the institutional actors, perhaps the most significant outcome was the introduction of technology incubators, development centres and techno-parks, which provide favourable conditions especially for start-ups and high technology SMEs. However, unlike the examples of

Taiwan's Hsinchu Park and Silicon Valley, which specifically aimed at hosting IT firms (Kim and von Tunzelmann, 1998) and accelerating the flow of knowledge between firms by all means, Turkey could not create a techno-park specialized in one specific industry. Firms in techno-parks located in close proximity to universities mostly aim at improving university-industry relations, but not inter-firm interactions. The Turkish S&T policy regrettably lacks the latter view. Moreover, the Turkish S&T policy has been largely downgraded to R&D policy on the whole. What is being done especially since 1997 is almost entirely about R&D.

Drawbacks faced during the implementation of policies for a national innovation system and the necessity to adjust to European Union innovation policies have forced the policy makers to change their policies very recently towards regional policies. A 'Draft law on the establishment, coordination and duties of regional development agencies' was submitted to the Parliament in February 2005. However, sectoral differences are not yet attracting any attention or discussed at all at the policy level.

Last but not least, according to the recent figures, approximately 50% of the economy is informal in Turkey. This means that half of the companies are not actually registered in the economy at all and will not benefit from any activities arranged as a result of science and technology policy measures. This issue has not been raised in any policy documents to date.

4.4.2 Knowledge Networks

This section deals with the flow of knowledge components of the innovation system between firms and other actors in Turkey. Interactions between the actors of the innovation system in Turkey are largely confined to the final period from 1997 to 2005. This background information is useful to present before the much-focussed empirical analyses of knowledge networks are set out in Chapters 6 and 7.

4.4.2.1 Actors in Knowledge Networks

As discussed in Chapter 2, knowledge flows among firms and between firms and other actors such as universities and research institutes in an innovation system.

In Turkey there were 78 universities located throughout the country in 2005. In a few strong universities located in big cities like Istanbul, Ankara and Izmir, engineering faculties have strong backgrounds. In such cases, these departments are always known and contacted by actively knowledge-seeking firms. So, these departments can encourage firms to start research projects or provide PhD places for their engineers.

Public research institutes and the R&D institutes of TUBITAK are mostly well known to the firms for their experimental facilities such as measurement, testing, training activities rather than being a partner in collaborative research projects with firms. The research institutes are so poorly managed and ineffective that the most structured one, the TUBITAK Marmara Research Centre, has been the focus of the policy measure of 'restructuring R&D institutions'. As Elci (2005:52) mentions, this intended MAM[41] to become more industry-oriented and achieve sustainability in the long run. For this purpose, the managerial and organisational capabilities of MAM were to be enhanced; profit centres would be established for its research institutes; internal contract management capacity be strengthened; and investments for upgrading its infrastructure and laboratory facilities, together with a techno-park facility would be supported for transforming the result of R&D activities into marketable products and services.

The universities recruit the vast majority of the country's researchers. As shown in Table 4.10 the number of researchers (full-time equivalent) in higher education was 24,735 in 2004. However, from 1990 to 2004, the share of universities in accommodating researchers decreased from 75% to 62% whilst the share of business enterprises doubled from 10% to 22%.

Table 4.10 Researchers by sector of employment (full-time equivalent and percent of total)

	Business enterprise	**% business enterprise**	**Government**	**% government**	**Higher education**	**% higher education**
1990	1168	10.4%	1637	14.6%	8420	75%
2002	3697	15.4%	2754	11.5%	17544	73.1%
2004	8831	22.1	6393	16%	24735	61.9%

Source: TURKSTAT (1997a, 2005, 2006).

[41] The most well-known TUBITAK research institute is the Marmara Research Centre (MAM) located in Izmit close to Istanbul.

However, the quality of researchers in the universities is questionable. For instance, TUBITAK-TIDEB research grants and TTGV research loans have been successful applications in encouraging especially high-technology SMEs to start up research projects. These grants and loans deliberately asked for interaction of the firm with a university. However, the findings of this thesis shows that higher-technology firms with skilled human resources were almost always frustrated in their relations with research institutes and universities except for using their experimental facilities. This was not the case for medium-low technology firms. This points out to a rather systematic problem in the Turkish innovation system, which indeed originates from the higher education system. Publication statistics of Turkish researchers at the science and engineering departments of universities in 2003 are presented in Table 4.11. The ranking of Turkey in the specified fields of science lags well behind the developed countries. If Turkey wishes to be productive in critical technologies such as ICT, advanced materials or biotechnology as it is always highlighted in each policy document; it has to address the skilled human resources problem. As the knowledge-based economy requires new skills and competencies, the quality of human resources is the major factor behind the invention and diffusion of technology.

Table 4.11 Science and engineering indicators for Turkey in 2003

	Published articles in journals in SCI index (% of total of 6224)	**Ranking of Turkey among other countries**
Clinical medicine	45	43
Biomedicine	7.2	38
Biology	7.6	Not in first 45
Chemistry	11.2	Not in first 45
Physics	8.9	44
Engineering & Technology	10.9	Not in first 45

Source: Bekaroglu (2006).

The roots of problems faced by the higher education system indeed lie in the education system of Turkey. Half of Turkey’s 14-17 age population does not have a high school degree and only one fourth of the 18-21 age population are graduates of universities. Vocational and technical education, which has the objective to enable individuals to acquire professional skills and to start their own businesses, is not at the desired level (see Tables 4.11 and 4.12). The Ministry of Education has taken Germany as an example to improve vocational education and even introduced some programmes for vocational school students to be trained practically in SMEs, yet these programmes do not have solid foundations and are not adequately active and efficient (EC & KOSGEB, 2002:5).

Table 4.12 School graduates by level of education and by years (%)

	2002-03	2003-04	2004-05
Primary education (8 years - compulsory) (students aged 6 to 13)	94.4	93.5	93.3
Secondary education (3-4 years) (students aged 14 to 17)	49.1	54.1	54.5
a) High school	31.6	34.3	33.7
b) Vocational school	17.6	19.8	20.8
Higher education (4-6 years) (students aged 18 to 21/23)	23.1	24.5	26.5

Source: SPO (2006b:111).

4.4.2.2 System Interactions

An innovation system is identified with the intensity of interactions among its actors. The greater the intensity of knowledge networks, the stronger is the innovation system, and vice versa. The long implemented policy framework for a Turkish national innovation system could not create the necessary impetus for establishing systemic interactions among its actors, namely university-industry, research institute-industry, or firm-firm linkages. This problem has been spotted and raised in every policy document; yet there has not been any study conducted to understand the nature of interactions among the system's actors.

To encourage firm-university interactions, a number of technology development centres and techno-parks hosting high-technology start-up firms have been established during the last five years. It is hoped that these incubators would provide a favourable habitat for university-firm and research institute-firm interactions. There have not been any surveys to find out the effects of incubators on university-firm research interactions, for instance regarding the number of joint research projects started and completed. The majority of the tenants of these incubators are consultancy firms and IT firms. I personally observed during my visits to these centres that IT firms do well in these incubators. Turkey's ICT patents as a percentage of total national patents filed at the European Patent Institute was around 12% in 1997 (OECD, 2001:25). Manufacturing sector firms in incubators, however, have 'testing and measuring services' as the strongest type of relation with the universities.

There are two university-industry research centres in Turkey: the Adana University - Industry Research Centre, which was founded within Cukurova University's organization in June 2000, with 39 members, mainly carries out joint projects on 'Production based on High Technology' with regional industrial establishments in fields like textiles, machinery and metal construction, and industrial automation and software by using 'Advanced Production Technologies' (EC &KOSGEB, 2002:27). Indeed, except for software, these industries are classified within medium-low and low technology industries in OECD.

The second one is the Ceramic Research Centre, which was established in 1998 within Eskisehir Anadolu University. 13 industrial enterprises are members of the centre. Laboratories in the Ceramic Research Centre are equipped adequately for conducting comprehensive research projects or conformity tests (EC & KOSGEB, 2002:26-7). In 2001, I paid a visit to this centre and interviewed the head of the centre. The researchers endowed with the knowledge of technical ceramics worked with large firms operating in the field of conventional ceramics used as tiles, sanitary materials, etc. and introduced them to the techniques and knowledge to produce technical ceramics. However, it was not possible for this centre to contact the majority of the SMEs operating in this field. The SMEs operating in advanced materials are scattered across the country by location, most of them located in Istanbul, but the research centre is located in Eskisehir at a minimum of 4 hours' driving distance from Istanbul. Therefore, there are certain difficulties in establishing contacts with SMEs. Policy should focus on methods for how to establish contacts with SMEs located further from these centres. Also, the Turkish industrial structure is determined by the dominance of medium-low and low technology industries, rather than high technology industries. Therefore, targets set for excelling in high technology industries need complementary approaches to simply building incubators. There are structural reasons as hurdles to why systemic interactions could not be enhanced among the universities and firms for setting up high technology SMEs, although there are efforts to establish incubators and research centres.

The policy documents and its implementations focus on firms' interactions with universities and research institutes only. Supplier firms and other firms are also vital sources of knowledge. However, this is not included in the scope of science and technology policy in Turkey. This study presents and discusses the findings from such interactions in Chapters 6 and 7.

Interactions of firms with foreign actors are also out of the scope of science and technology policy design in Turkey. Because a 'national innovation system' is designed, its boundaries are determined with the boundaries of Turkey. Indeed, it can be quite possible that the firms in the materials industry in Turkey have as many interactions with foreign actors as they do have with domestic actors. Moreover, the content of the interaction may go beyond simple production technology transfer. This study also presents and discusses the findings from such interactions in Chapters 6 and 7.

4.4.3 Summary

Especially during the last period, governmental bodies have been trying to design a national innovation system in Turkey at the policy level. These efforts have been largely isolated from the firms and the industries. Moreover, the innovation system concept was downgraded to the support of R&D activities undertaken in the industries or the number of researchers in the country. The only positive step has been the establishment of technology development centres for SMEs and techno-parks for larger firms. However, in the rest of the industries, where firms are not located in techno-parks, there have been some limited improvements as well.

The S&T policies in Turkey aimed at improving interactions between firms and research institutions, but the inter-firm interactions received no attention in the policy documents.

This thesis tries to show that, in the particular industry of materials in Turkey, the underlying aspects of an innovation system are effective technology acquisition that would increase firm-level technological capabilities and the increase in firm interactions. The efforts of governmental bodies and the measures taken would only be effective once the firms are technologically ready to take these efforts further.

4.5 Conclusion

As described in the above sections, the Turkish state predominantly tried to draw a framework by taking decisions, approving legislation and certain applications, for a functioning *national* innovation system. Other than the formation of a strong policy background, these efforts did not yield much practical outcomes from a systemic interactions point of view. Lack of co-operation and commitment among the policy actors of the system has mostly been put forward as the reason for this failure.

As a remedy for the ineffectiveness of the national innovation system, experts have recently started to emphasize the need for regional development policies in Turkey. These ideas come aboard at a time along with Turkey's efforts to adjust itself to European Union policies. If a more flexible way of thinking is applied, it will be noticed that the borders of Turkey's emerging innovation system might actually be larger than it is thought to be. The following chapters aim to look for answers to this question of to what extent the technology acquisition in the firms contribute to firm-level technological capability accumulation, and whether improved capabilities pave the way for more interactions in the firms with both domestic and foreign partners.

CHAPTER 5 TECHNOLOGY TRANSFER AND TECHNOLOGICAL CAPABILITY ACCUMULATION

5.1 Introduction

This thesis investigates the emergence of innovation systems in the developing country context, by first analysing the contribution of the technology transfer process in the firm to improve its technological capabilities (in this chapter) and secondly by analysing the influence of improved capabilities on the emergence of the innovation system (in Chapter 6). Since the acquired skills and knowledge might be transformed into technical change activities through interactions between elements of the system, technological capabilities act as a bridge from the technology transfer process towards innovation systems. Innovative capacity itself has a strong relation with technological capabilities acquired through learning by means of technology transfer activities.

This chapter analyses the ways in which firms in the materials industry acquired their technology and their paths of technological capability accumulation during the period from 1967 to 2001 in Turkey. It aims to answer the research question:
"How does the transfer of technology influence technological capabilities at the firm level in the materials industry in Turkey?"

In section 3.6.1 of the Methodology chapter, elements of the technology transfer process were introduced as drawn from the literature. There are three main sets of elements that influence technological capability accumulation in a firm: mode of technology transfer, the existing knowledge base in the firm, and the intensity of effort by the firm to accumulate technological capabilities. Section 3.6.1 also presented the variables (indicators) for explaining the above-mentioned elements, namely managerial skills, skilled personnel, search into contributor and technology as well as R&D and design activities in the firm.

For this analysis, the main dataset consisting of 408 observations is used. This categorical dataset is formed by face-to-face interviews with 19 firms in the materials industry. As previously explained in Section 3.4.7, each of the 408 observations represents a knowledge link between the firm and any one of the partners in the system of innovation, including partners located outside Turkey and also the firm's own intra-firm resources. Knowledge links are attributes of technology projects. Within each technology project, information was sought about what technology was acquired and how, through each of several ‘knowledge links’ involving different sources. Since there were on average 1.4 actively used links per project, the total of 289 projects provided a total of 408 observations, which constitutes the main database.

This chapter is designed in four main parts. Section 5.2 presents the dataset and the frequencies of the variable categories in the dataset, as well as the change over time regarding these variable categories. In Section 5.3 cross-tabulation analyses of the dependent variable with each of the explanatory variables are presented as well as the statistical tests. Section 5.4 presents the results obtained from the econometric analyses (multinomial logistic regression models). Finally, Section 5.5 forms the conclusions.

5.2 Characteristics of Technology Transfer in Firms in the Materials Industry in Turkey

This descriptive section aims to present the data obtained in face-to-face interviews in the firms. It mainly focuses on frequency elaborations of knowledge links pertaining to the variable categories. In doing this, as well as the industry in general, the distinction between the two different segments of the industry – i.e. science-based technology and mature technology – is highlighted.

Frequencies of knowledge links pertaining to the categories of variables are presented in this section for all firms and compared across science-based and mature technology firms in Tables 5.1 to 5.3. As widely discussed in the earlier chapters, technological capability accumulation is a function of the mode of technology transfer first from foreign sources in the form of technology imports and FDI, or second from domestic sources through own in-house efforts such as reverse-engineering (Kim and Kim, 1985; Kim, 1997), and in most ideal cases these two would complement each other in a developing country context (Bell and Pavitt, 1993: 193). Capability accumulation is also a function of the absorptive capacity level of the firm (Cohen and Levinthal, 1990), fragmented according to the prior knowledge base and intensity of effort by the firm (Kim, 1997). Therefore, ‘mode of technology transfer’, ‘manager specifications related to industrial and academic experiences’, ‘percentage of researchers in the firm’, ‘search into contributor', 'search into technology to be received', 'R&D activities in the firm' and 'design activities in the firm' stand for the explanatory variables of the analysis in this section. 'Increment in capability' represents the dependent variable. The variables tested here are described in detail in section 3.6.1 above. The sections to follow will present data from the Turkish materials industry within this context.

The results of non-parametric chi-square statistics[42] are provided for the variables and for the contingency tables. Simple frequency analysis is followed by a dynamic analysis in Section 5.2.4, tracing changes over time in the characteristics of technology transfer and capability accumulation in the firms.

5.2.1 Modes of Technology Transfer

As explained earlier in section 3.6.1.1 and illustrated in Table 3.7 of Chapter 3, firms have broadly four main modes to acquire the technology they need, namely: (i) arm's length activities ranging from sole import of machinery to licensing; (ii) firm-endogenous activities such as reverse-engineering or in-house R&D projects; (iii) collaborative agreements that are mainly based on bi-lateral knowledge flow between the firm and a partner; and (iv) foreign direct investment (FDI) also covering brain gain besides joint ventures and subsidiaries.

Table 5.1 suggests that firms in the materials industry sourced their technologies mainly by way of collaborative agreement type relations with other agents in the innovation system during the period of 1967-2001 (44.1 per cent of all links). In the second place, they relied on arm's length activities (30.9 per cent). Firm-endogenous activities accounted for almost one fifth of their links. Foreign direct investment did not have a

[42] For the description of categorical type of data used in the capability analysis, non-parametric chi-square tests are used. This test tabulates a variable into categories and tests the hypothesis that the observed frequencies do not differ from their expected values. The very low significance values show that categories of variables do really differ from each other. Also, chi square is a non-parametric test of statistical significance for bivariate tabular analysis. Typically, the hypothesis tested with chi square is whether or not two different samples are different enough in some characteristic or aspect of their behaviour that we can generalize from our samples that the populations from which our samples are drawn are also different in the behaviour or characteristic.

considerable share (6.4%) and it was very weak within the whole economy in Turkey during that period.[43]

Table 5.1 Distribution of links by mode of technology transfer and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
Mode of Technology Transfer (TECHTRANS)	**Count**	**% links**	**Count**	**% links**	**Count**	**% links**
Arm's length activity	126	30.9%	51	23.5%	75	39.3%
Firm-endogenous activity	76	18.6%	41	18.9%	35	18.3%
Collaborative agreements	180	44.1%	103	47.5%	77	40.3%
FDI	26	6.4%	22	10.1%	4	2.1%
All	408	100.0%	217	100.0%	191	100.0%
TECHTRANS *(*Chi-Square Test, asymp. sig.*)*	0.000		0.000		0.000	
FIRMTYPE vs. TECHTRANS (Pearson Chi-square, asymp.sig. 2-sided)			0.000			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews.

In Table 5.1, the Pearson chi-square test for FIRMTYPE vs. TECHTRANS is significant at the 1% level, indicating that the two variables are associated with the differences between science-based and mature branches. This implies that the two segments of the industry behaved quite differently in the ways they acquired their technology. By inspection, it appears that science-based technology firms made much ***less*** use of arm's length means than mature technology firms (39.3% and 23.5%), while making relatively ***more*** use of both collaborative agreements (47.5% and 40.3%) and FDI (10.1% and 2.1%).

5.2.2 The Existing Knowledge Base in the Firm

Empirical evidence from the existing literature shows that firm-level capability accumulation is strongly influenced by the firm's absorptive capacity (Kim and Kim 1985; Kim 1997). The first element of absorptive capacity, namely the existing

[43] The chi-square tests for the TECHTRANS variable are significant at 1% level for all firms, science-based technology and mature technology firms, showing that the categories of this variable really differ from each other.

knowledge base is represented by three indicators in this research: (i) the percentage of skilled personnel in total employees in the firm; (ii) the manager's academic and research experience and (iii) the manager's industrial and work experience. The tacit character of knowledge is human-embodied. Therefore, studying the above-mentioned variables dealing directly with human factor in the firms can only capture its effects on capability accumulation.

Table 5.2 Distribution of links by percentage of researcher, managerial experiences and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
THE EXISTING KNOWLEDGE BASE OF THE FIRM	**Count**	**% links**	**Count**	**% links**	**Count**	**% links**
Percent of researchers/engineers to total employees (PRES)						
More than 50%	48	11.8%	33	15.2%	15	7.9%
Less than 49%	360	88.2%	184	84.8%	176	92.1%
Manager specifications related to education and academic experiences (MANACD)						
Degree from university abroad	92	22.5%	71	32.7%	21	11.0%
Degree from national university	292	71.6%	123	56.7%	169	88.5%
No degree	24	5.9%	23	10.6%	1	0.5%
Manager specifications related to industrial experiences (MANIND)						
Work experience at a firm abroad	46	11.3%	42	19.4%	4	2.1%
Work experience at a domestic firm	358	87.7%	171	78.8%	187	97.9%
No experience	4	1.0%	4	1.8%	0	0.0%
All	408	100.0%	217	100.0%	191	100.0%
Chi-Square Tests for (asymp. sig.)						
PRES	0.000		0.000		0.000	
MANACD	0.000		0.000		0.000	
MANIND	0.000		0.000		0.000	
Pearson Chi-squares for (asymp.sig.2-sided)						
FIRMTYPE vs. PRES			0.021			
FIRMTYPE vs. MANACD			0.000			
FIRMTYPE vs. MANIND			0.000			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews.

Table 5.2 suggests that for all firms in both segments of the industry, only during one in ten knowledge links did firms have researchers as more than 50 per cent of their total employees. However, more than 90 per cent of all links were basically conducted with university graduate managers who previously had work experience either inside the country or abroad.[44]

In Table 5.2, the Pearson chi-square test for FIRMTYPE vs. PRES is significant at the 5% level, for FIRMTYPE vs. MANACD and for FIRMTYPE vs. MANIND it is significant at the 1% level, indicating that that the two variables in each set are associated with the branch of the industry. This implies that the two segments of the industry behaved quite differently in terms of their existing knowledge bases and in particularly the knowledge held in their human workforce. First, the proportion of links that occurred at a time when the firm had more than 50% of researchers in its workforce was almost twice as ***large*** in science-based technology firms as in mature technology firms (15.2% and 7.9%). Secondly, the proportion of links conducted by firms employing foreign-educated managers was considerably ***larger*** in science-based technology firms than in mature technology firms (32.7% and 11.0%). And thirdly, the proportion of links conducted by firms employing managers with work experience abroad was substantially ***larger*** in science-based technology firms than the mature technology firms (19.4% and 2.1%). In the mature segment of the industry, managers who had graduated from national universities and with work experience at home country dominated.

5.2.3 The Intensity of Effort by the Firm

The second important element of absorptive capacity is the intensity of effort exerted by the firm. This is represented in this research by four indicators: (i) the preparatory effort in the firm involving search into the partner; (ii) the preparatory effort in the firm involving search into the technology to be received; (iii) R&D activities; and (iv) design activities undertaken by the firm. These activities are substantial for knowledge internalisation in the firm within the framework of dynamics of learning (Kim, 1997) and complementary to the existing knowledge base.

[44] The chi-square tests for the PRES, MANACD and MANIND variables are significant at 1% level for all firms, science-based technology and mature technology firms, showing that the categories of these variables really differ from each other.

Table 5.3 Distribution of links by search into knowledge contributor and technology, R&D and design activities and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
THE INTENSITY OF EFFORT IN THE FIRM	**Count**	**% links**	**Count**	**% links**	**Count**	**% links**
Search into knowledge contributor (SECONT)						
Experience-based search	336	82.4%	180	82.9%	156	81.7%
None or simple search	72	17.6%	37	17.1%	35	18.3%
Search into technology to be received from knowledge contributor (SETECH)						
Knowledge-based search	378	92.6%	208	95.9%	170	89.0%
None or simple search	30	7.4%	9	4.1%	21	11.0%
R&D activities (RND)						
Primary: at the firm's own facilities	29	7.1%	26	12.0%	3	1.6%
Active: at the partner's facilities	41	10.0%	28	12.9%	13	6.8%
None	338	82.8%	163	75.1%	175	91.6%
Design activities (DESIGN)						
Non-trivial	115	28.2%	68	31.3%	47	24.6%
Trivial and none	293	71.8%	149	68.7%	144	75.4%
All	408	100.0%	217	100.0%	191	100.0%
Chi-Square Tests for (asymp. sig.)						
SECONT	0.000		0.000		0.000	
SETECH	0.000		0.000		0.000	
RND	0.000		0.000		0.000	
DESIGN	0.000		0.000		0.000	
Pearson Chi-squares for (asymp.sig. 2-sided)						
FIRMTYPE vs. SECONT			0.736			
FIRMTYPE vs. SETECH			0.008			
FIRMTYPE vs. RND			0.000			
FIRMTYPE vs. DESIGN			0.132			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews.

Table 5.3 suggests that for all firms in both segments of the industry, in at least four out of every five linkages, the partner and the technology to be received was subject to pre-search by the firms. In contrast, in at most one out of five of the links the firms conducted R&D and in at most one out of three links some kind of design activity.[45]

In Table 5.3, the Pearson chi-square tests for FIRMTYPE vs. SECONT and for FIRMTYPE vs. DESIGN are not significant indicating that the two variables in each set are not associated with the differences between the two branches of industry. This implies that the two segments of the industry behaved similarly regarding the search into contributor and design activities elements of the intensity of effort. By inspection, it appears that the proportion of links that concerned experience-based pre-search into contributor in both segments of the industry did not differ (82.9% in the science-based segment and 81.7% in the mature segment). Also, the proportion of links with non-trivial design activities was ***not*** significantly ***greater*** in science-based technology firms than mature technology firms (31.3% and 24.6%).

However, the Pearson chi-square tests for FIRMTYPE vs. SETECH and for FIRMTYPE vs. RND are significant at 1% level, indicating that that the two variables are associated with differences between branches. This implies that the two segments of the industry behaved quite differently regarding pre-search into technology and the R&D activities elements of the intensity of effort in the firm. The proportion of links that concerned knowledge-based pre-search into the technology to be received by the firm was slightly ***greater*** in science-based technology firms than mature technology firms (95.9% and 89%). The proportion of links involving primary and active R&D, conducted on the firms' own premises and partner's premises, was considerably ***greater*** in science-based technology firms than that of mature technology firms (12% and 1.6% for primary R&D; 12.9% and 6.8% for active R&D).

5.2.4 Changing Patterns of the Technology Transfer Process

This section deals with the changes in firms' characteristics of technology transfer over time. As detailed in Chapter 3, three major policy-defined sub-periods are configured representing the whole time span covering the research: (i) 1967-1981, (ii) 1982-1996, and (iii) 1997-2001. The 1967-1981 sub-period was characterised by the effective

[45] The chi-square tests for the SECONT, SETECH, RND and DESIGN variables are significant at 1% level for all firms, science-based technology and mature technology firms, showing that the categories of these variables really differ from each other.

implementation of import-substitution policies in the Turkish economy. 1982-1996 was a transition period during which the outcomes of a major policy shift to export-orientation were gradually experienced .The 1997-2001 sub-period was distinguished by the full influences of liberalisation on the economy.[46]

In this section, cross-tabulations (or contingency tables) display the relationships between sub-periods and each of the variables of the technology transfer and technological capability analysis. Major changes were observed in firms' technology transfer characteristics from 1967 to 2001. The sub-sections below highlight these changes.

5.2.4.1 Mode of Technology Transfer

In Table 5.4, drawn from Appendix Tables C.1 to C.3, the Pearson chi-square test for PERIOD vs. TECHTRANS is significant at the 1% level when tested for all firms, indicating that the two variables are associated with the distribution of links. This implies that the three sub-periods showed significant differences in the ways that firms acquired their technologies. The industry, on the whole, was moving towards more collaborative modes of technology transfer over time. For example, during the 1967-1981 sub-period, firms were likely to use collaborative agreement mode of technology transfer methods in less than one in five of their knowledge links. During 1997-2001, that proportion was nearly half of their links, 49.2%. In contrast, the industry was moving away from the arm's length modes of technology transfer over time. During the 1967-1981 sub-period, firms were likely to use the arm's length mode of technology transfer methods in more than half of their knowledge links, 59.3%. During 1997-2001, that proportion was one in four of their links, 25.4%.

Table 5.4 further shows that, when controlling for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. TECHTRANS is significant at the 1% level for science-based technology firms, indicating that the two variables are associated; while it is significant at the 10% level for mature technology firms, indicating a suggestive but not conclusive relationship between the two variables. This implies that for science-based technology firms the three sub-periods showed

[46] Details of policy changes in the Turkish economy are widely discussed in Section 4.2 of Chapter 4.

differences in the ways that these firms acquired their technologies, but for mature technology firms these differences between the three sub-periods are less pronounced.

Table 5.4 Distribution of links by mode of technology transfer, period and industry categories (percentage of linkages)

	For all firms[a]			For science-based technology firms[b]			For mature technology firms[c]		
Periods	**1967-81**	**1982-96**	**1997-01**	**1967-81**	**1982-96**	**1997-01**	**1967-81**	**1982-96**	**1997-01**
Mode of technology transfer (TECHTRANS)									
Arm's length activity	59.3	34.8	25.4	63.6	27.3	17.8	56.3	43.8	34.2
Firm-endogenous activity	18.5	12.1	22.5	18.2	6.5	26.4	18.8	18.8	18.0
Collaborative agreements	14.8	41.1	49.2	9.1	48.1	50.4	18.8	32.8	47.7
FDI	7.4	12.1	2.9	9.1	18.2	5.4	6.3	4.7	0.0
All	6.6	34.6	58.8	5.1	35.5	59.4	8.4	33.5	58.1
Pearson Chi-square Tests	(asymp. sig. 2-sided)			(asymp. sig. 2-sided)			(asymp. sig. 2-sided)		
PERIOD vs. TECHTRANS	0.000			0.000			0.058		

a N=408, b N=217, c N=191.
Source: Author's interviews.

By inspection of Table 5.4, it appears that in both segments of the industry links with collaborative agreement modes of technology transfer were increasing over time, while links with arm's length modes were decreasing. However, these changes were slightly more influential in the science-based segment of the industry. During the 1967-1981 sub-period, the science-based segment of the industry had a ***lower*** proportion of the collaborative agreement mode of technology transfer linkages than the mature technology firms (9.1% and 18.8%); but in 1997-2001 it had just a little ***higher*** proportion (50.4% and 47.7%). In 1997-2001 the science-based technology firms had a much ***lower*** proportion of the arm's length activity mode of technology transfer linkages than mature technology firms (17.8% and 34.2%); and ***higher*** proportion of firm-endogenous activity and the FDI mode of technology transfer linkages than the mature technology firms (26.4% and 18.0%; 5.4% and 0.0%, respectively).

5.2.4.2 The Existing Knowledge Base in the Firm

In Table 5.5, drawn from Appendix tables C.4 to C.12, the Pearson chi-square test for PERIOD vs. MANACD is significant at the 1% level, indicating that the two variables are associated with the differences in firms' knowledge bases; while for PERIOD vs. PRES and PERIOD vs. MANIND they are significant at the 10% level when tested for all firms, indicating that the relationship between these two variables is suggestive but not conclusive. These results imply that the three sub-periods showed differences between firms' existing knowledge bases regarding the academic skills of their managers and might have shown some differences regarding the percentage of researchers in the firm and the industrial skills of their managers. Thus, the human resources in the firms were shifting towards a more skilled inventory over time. For example, during the 1967-1981 sub-period, firms were likely to have researchers or engineers as more than 50% of their employees in none of their knowledge links; but by 1997-2001, that proportion was 14.2% of their links. In addition, during 1967-1981, firms were likely to have overseas-trained managers in 14.8% of their knowledge links, but by 1997-2001 that proportion was 25.8% per cent with a considerable number of PhD holders in the fields of science from universities abroad.

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. PRES is non-significant both for science-based and mature technology firms, indicating that the two variables are not associated with this context. This suggests that the three sub-periods did not show any differences regarding the percentage of researchers in the firm in either firm type. Even during the last sub-period from 1997 to 2001, both science- based and mature technology firms' proportions of links with researchers who represented less than 49% of their employees were still considerably high (81.4% and 91%, respectively). Firms did not show remarkable differences in their proportions of links with researchers who constituted more than 50% of their employees from the second to the third sub-period. However, the science-based technology firms had a ***larger*** proportion of linkages with researchers or engineers as more than 50% of their employees than the mature technology firms in that sub-period (18.6% and 9.0%).

Table 5.5 Distribution of links by existing knowledge base in the firm, period and industry categories (percentage of linkages)

THE EXISTING KNOWLEDGE BASE IN THE FIRM	For all firms[a]			For science-based technology firms[b]			For mature technology firms[c]		
Periods	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01
Percentage of researchers/engineers to total employees (PRES)									
More than 50%	0.0	9.9	14.2	0.0	11.7	18.6	0.0	7.8	9.0
Less than 49%	100.0	90.1	85.8	100.0	88.3	81.4	100.0	92.2	91.0
Manager specifications related to education and academic experiences (MANACD)									
Degree from university abroad	14.8	18.4	25.8	0.0	33.8	34.9	25.0	0.0	15.3
Degree from national university	81.5	69.5	71.7	100.0	44.2	60.5	68.8	100.0	84.7
No degree	3.7	12.1	2.5	0.0	22.1	4.7	6.2	0.0	0.0
Manager specifications related to industrial experiences (MANIND)									
Work experience at a firm abroad	14.8	8.5	12.5	0.0	15.6	23.3	25.0	0.0	0.0
Work experience at a domestic firm	85.2	88.7	87.5	100.0	79.2	76.7	75.0	100.0	100.0
No experience	0.0	2.8	0.0	0.0	5.2	0.0	0.0	0.0	0.0
All	6.6	34.6	58.8	5.1	35.5	59.4	8.4	33.5	58.1
Pearson Chi-square Tests	**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**		
PERIOD vs. PRES	0.067			0.145			0.456		
PERIOD vs. MANACD	0.002			0.000			0.000		
PERIOD vs. MANIND	0.057			0.020			0.000		

a N=408, b N=217, c N=191.
Source: Author's interviews.

However, when controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. MANACD is significant at the 1% level both for science-based and mature technology firms, indicating that the two variables are associated with this context. This suggests that the three sub-periods showed differences regarding the manager specifications related to academic experiences in both of the firm types. In Table 5.5, it appears that the science-based and the mature segments of the industry behaved differently. The science-based technology firms had a much ***larger*** proportion of linkages conducted by managers who were overseas-trained than the mature technology firms in the final sub-period (34.9% and 15.3%). In contrast, the mature technology firms had a much ***larger*** proportion of linkages conducted by managers who were overseas-trained than the science-based technology firms in the first sub-period (25.0% and 0.0%, respectively). This is probably due to the fact that during the sub-period 1967 to 1981, mature technology firms' activities could be considered as those involving novel technologies[47] and because of that they might have needed overseas-trained managers.

Lastly, when controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. MANIND is significant at the 5% level for science-based and at the 1% level mature technology firms, indicating that the two variables are associated here. This suggests that the three sub-periods showed differences regarding the manager specifications related to industrial experiences in both firm types. By inspection, it appears that the science-based technology firms had a much ***larger*** proportion of linkages conducted by managers who had overseas work experience than the mature technology firms in the final sub-period (23.3% and 0.0%, respectively). In contrast, the mature technology firms had a much ***larger*** proportion of linkages conducted by managers who had overseas work experience than the science-based technology firms in the first sub-period (25.0% and 0.0%, respectively). This is again probably due to the fact that during the sub-period 1967 to 1981, mature technology firms' activities were supposed to be novel technologies and that is why they might have needed overseas experienced managers then.

Having work experience abroad during the final sub-period is more an attribute of science-based technology firms' managers. It must be noted that there has been no particularly planned and massive government-led programmes for educating people abroad in Turkey as there was in the remarkable example of South Korea. Thus, this initial finding about the science-based technology firm managers' having past and

[47] For instance, small bulk metal composite products, used in the automotive industry, are produced by powder metallurgy techniques of cold or hot pressing (see Appendix A.6.1). Although today these methods are considered as low to medium technology processes, during the 1970s they would be regarded as high technology processes particularly in a developing country where industrial policies were bound by import-substitution. Therefore, to be able to choose and then use these technologies firms would at least need managers with specific knowledge of these processes.

present links with foreign educational institutions should be regarded as purely individual efforts.

5.2.4.3 The Intensity of Effort by the Firm

In Table 5.6, drawn from Appendix tables C.13 to C.24, the Pearson chi-square tests for PERIOD vs. SECONT and PERIOD vs. SETECH are not significant, indicating that the two variables are not associated with differences in intensity of effort; while for PERIOD vs. RND and PERIOD vs. DESIGN they are significant at the 1% level when tested for all firms, indicating that the relationship between these two sets of variables are significant. These results suggest that the three sub-periods did not show any differences in firms' intensity of effort regarding the pre-search activities of firms, but showed differences regarding the R&D and design activities in the firms.

The proportions of links that firms conducted experience- and knowledge-based search into contributor and technology did not change much from 1967-1981 to 1997-2001 (74.1% to 82.1% and 85.2% to 92.9%, respectively). Besides, these proportions were already high during the earlier sub-periods. Firms spent considerable effort searching into the technology they would receive and the partner they would collaborate with prior to actual collaboration at least in three out of four links even in the earlier sub-periods. So, from now on, these two variables will be abandoned in the further analyses[48]. On the other hand, the research activities were intensifying over time, especially for R&D and design activities undertaken in the firms. For example, during 1967-1981, firms were likely to conduct primary and active R&D activities on their own premises and on the partner's premises in none of their knowledge links, but by 1997-2001 that proportion was 11.7% and 14.2% of their links, respectively. Moreover, in 1967-1981, firms were likely to conduct non-trivial design activities in 14.8% of their knowledge links, but by 1997-2001, that proportion had risen to 40.4%.

Table 5.6 also shows that, controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. RND is significant at the 1% level for science-based technology firms, indicating that the two variables are associated with differences

[48] Also, there is no statistically significant association between the type of firm and search into contributor when tested for all firms (see Table 5.3).

in intensity of effort and the test is significant at the 10% level for mature technology firms, indicating that the evidence of a relationship between the two variables is suggestive but not conclusive in this context. This implies that the three sub-periods showed differences regarding the R&D activities in the science-based segment of the industry, and they might also have shown differences for R&D activities in the mature segment.

Table 5.6 Distribution of links by intensity of effort by the firm, period and industry categories (per cent of linkages)

THE INTENSITY OF EFFORT IN THE FIRM	For all firms[a]			For science-based technology firms[b]			For mature technology firms[c]		
Periods	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01
Search into contributor (SECONT)									
Experience-based research	74.1	84.4	82.1	54.5	85.7	83.7	87.5	82.8	80.2
Simple or none	25.9	15.6	17.9	45.5	14.3	16.3	12.5	17.2	19.8
Search into technology received from contributor (SETECH)									
Knowledge-based research	85.2	93.6	92.9	81.8	96.1	96.9	87.5	90.6	88.3
Simple or none	14.8	6.4	7.1	18.2	3.9	3.1	12.5	9.4	11.7
R&D activities (RND)									
Primary	0.0	0.7	11.7	0.0	1.3	19.4	0.0	0.0	2.7
Active	0.0	5.0	14.2	0.0	7.8	17.1	0.0	1.6	10.8
None	100.0	94.3	74.2	100.0	90.0	63.6	100.0	98.4	86.5
Design activities (DESIGN)									
Non-trivial	14.8	9.9	40.4	36.4	9.1	44.2	0.0	10.9	36.0
Trivial or none	85.2	90.1	59.6	63.6	90.9	55.8	100.0	89.1	64.0
All	6.6	34.6	58.8	5.1	35.5	59.4	8.4	33.5	58.1
Pearson Chi-square Tests	**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**		
PERIOD v. SECONT	0.429			0.034			0.747		
PERIOD v. SETECH	0.297			0.055			0.875		
PERIOD v. RND	0.000			0.000			0.056		
PERIOD v. DESIGN	0.000			0.000			0.000		

a N=408, b N=217, c N=191.
Source: Author's interviews.

By inspection of Table 5.6, it appears that the science-based and the mature segments of the industry behaved differently particularly regarding the primary R&D activities. The science-based technology firms had a considerably ***higher*** proportion of linkages with primary R&D activities than the mature technology firms in the sub-period 1997-2001 (19.4% and 2.7%), although neither kind of firms had any links where they conducted primary R&D activities during the initial sub-period of 1967-1981. The proportion of links with active R&D that the firms conducted in their partners' facilities - the partner usually being a university or a research institute - was also higher in science-based technology firms than the mature technology firms (17.1% and 10.8%).

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. DESIGN is significant both for science-based and mature technology firms, indicating that the two variables are associated with this context. This implies that the three sub-periods showed differences regarding the design activities in both firm types. In Table 5.6, it is seen that the science-based and the mature segments of the industry behaved differently regarding their non-trivial design activities. The science-based technology firms initially, in the sub-period 1967-1981, had a ***greater*** proportion of linkages where they conducted non-trivial design activities than the mature technology firms (36.4% and 0.0%). In the final sub-period they still had a ***greater*** proportion of such linkages (44.2% and 36.0%), however the mature technology firms had managed to improve their design skills by the final sub-period. Yet, whereas science-based firms' design activities were mostly the firm's own original designs of high technology products and processes, mature technology firms' design activities were mainly customer-guided recipes, where there was not a substantial input from the firm itself into this design activity. Also, they covered mostly mature techniques and products.

5.2.5 Summary

The current analysis has found that technology acquisition characteristics in firms in the materials industry in Turkey shifted over time towards collaborative and intra-firm relationships in which skilled labour force and R&D and design activities were increasingly involved. In these respects, the science-based segment of the industry had certain advantages over the mature segment.

The following sections will investigate the degree to which technological capability accumulation was influenced by these changes in technology acquisition characteristics in firms.

5.3 Technology Transfer and Technological Capabilities

The analysis in this section focuses on the relationship between key features of the way firms acquire technology and their paths of capability accumulation. It is tested whether the prior knowledge base in the firms – i.e. higher number of researchers, managers endowed with higher level of academic and industrial skills, and the intensity of effort in the firms – i.e. considerable effort exerted into R&D and design activities to acquire and internalise more knowledge are influential in determining the levels and paths of technological capability assimilation and accumulation. These will be tested more formally later in this chapter. Finally, as discussed in the views from the literature, whether the mode of technology transfer is influential for firm-level technological capabilities or not is also to be tested.

Cross-tabulations (or contingency tables) display the individual relationship between two variables. This section presents the findings of cross-tabulation analyses between the dependent variable 'increment in capability' and each of the explanatory variables of the technology transfer and technological capability analysis, regardless of the time dimension. Here, I searched for the association between the dependent variable 'increment in capability **at time t**' and the explanatory variables (pertaining to existing knowledge base and intensity of effort in the firm) also at time t. The latter is expected to influence the former with an immediate effect. The results relating to the materials industry in general are discussed and complemented with discussions about the significant highlights of science-based and mature segments of the industry. In addition, the results of statistical tests for cross-tabulations of the categorical data are presented. The database used in these analyses is the main dataset formed by 408 observations for knowledge links. Correspondence analysis plots are used as auxiliary tools to highlight and comment on the findings from the cross-tabulation analyses.[49]

[49] Correspondence analysis plots are available only for variables with more than two categories. Therefore, variables PRES and DESIGN do not have any correspondence analysis plots.

In order to specify the relationship between the characteristics of technology acquisition and the technological capability accumulation in firms, first capability accumulation needs to be discussed. The next section presents findings from this analysis.

5.3.1 Technological Capability Accumulation

The variable *Increment in Capability* serves for examining the role of technological capability in the analysis. Table 5.7 shows how different levels of capability increments are distributed within total links of firms and how they change by firm type. Increment in technological capabilities from each knowledge link is categorised in three as (i) capability increments in process and product development, (ii) capability increments in process and product improvement, (iii) capability increments in process operation or no capability acquired.

Table 5.7 Distribution of links by increment in capability and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
INCREMENT IN CAPABILITY (INCCAP)	**Count**	**% links**	**Count**	**% links**	**Count**	**% links**
Operational capability or no capability acquired	216	53.0%	101	46.5%	115	60.2%
Of which operational capability	187	45.8%	85	39.2%	102	53.4%
Of which no capability acquired	29	7.1%	16	7.4%	13	6.8%
Improvement of product or process technology	94	23.0%	51	23.5%	43	22.5%
Development of product or process technology	98	24.0%	65	30.0%	33	17.3%
All	408	100.0%	217	100.0%	191	100.0%
INCCAP *(Chi-Square Test, asymp. sig.)*	0.000		0.000		0.000	
FIRMTYPE vs. INCCAP (Pearson Chi-square, asymp.sig. 2-sided)			0.005			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews.

Table 5.7 suggests that, from 1967 to 2001, more than half of the firms' knowledge linkages yielded increments in operational capabilities or none at all (53.0%). The rest of their links yielded increments in process or product improvement capabilities and development capabilities (23.0% and 24.0%, respectively).[50]

In Table 5.7, the Pearson chi-square test for FIRMTYPE vs. INCCAP is significant at the 1% level, indicating that the two variables are associated with each other. This implies that the two segments of the industry behaved differently in terms of the level of additional technological capabilities they acquired from their knowledge links. By inspection, it appears that science-based technology firms acquired ***more*** product or process development capabilities and ***fewer*** operational capabilities from their knowledge links than the mature technology firms (30.0% and 17.3% of their links for development capabilities and 46.5% and 60.2% of their links for operational capabilities). However, the proportion of links that resulted in product or process improvement technologies did not vary between firm types (23.5% for the science-based segment and 22.5% for the mature segment). This general picture indicates the state of an industry with emphasis on process operation skills, yet with emerging technology imitation, generation and innovation skills.

In Table 5.8, drawn from Appendix Tables C.25, C.26 and C.27, the Pearson chi-square test for PERIOD vs. INCCAP is significant at the 1% level when tested for all firms, indicating that the two variables are associated with each other. This implies that the three sub-periods showed significant differences by the level of incremental technological capabilities that they acquired from their knowledge links. Over time, all firms increased their acquisition of development capabilities of a product or process from nil during the 1967-1981 sub-period to more than one-third of all links in the 1997-2001 sub-period and they almost halved their acquisition of operational capabilities from 1967-1981 to 1997-2001.

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. INCCAP is significant at the 1% level both for science-based and mature technology firms, indicating that the two variables are associated in this context. This implies that for both types of firms the three sub-periods showed differences by the

[50] The chi-square tests for INCCAP variable is significant at 1% level for all firms, science-based technology and mature technology firms, showing that the categories of this variable really differ from each other.

level of incremental technological capabilities that they acquired from their knowledge links.

Table 5.8 Distribution of links by increment in capability, period and industry categories (in percentage of links)

	For all firms[a]			For science-based technology firms[b]			For mature technology firms[c]		
Periods	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01
INCREMENT IN CAPABILITY (INCCAP)									
Operational capability or no capability acquired	96.3	66.7	40.0	100.0	61.0	33.3	93.8	73.4	47.4
Improvement of product or process technology	3.7	27.0	22.9	0.0	27.3	23.3	6.3	26.6	22.5
Development of product or process technology	0.0	6.4	37.1	0.0	11.7	43.4	0.0	0.0	29.7
All links (count)	27	141	240	11	77	129	16	64	111
Pearson Chi-square Tests	**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**		
PERIOD vs. INCCAP	0.000			0.000			0.000		

a N=408, b N=217, c N=191.
Source: Author's interviews.

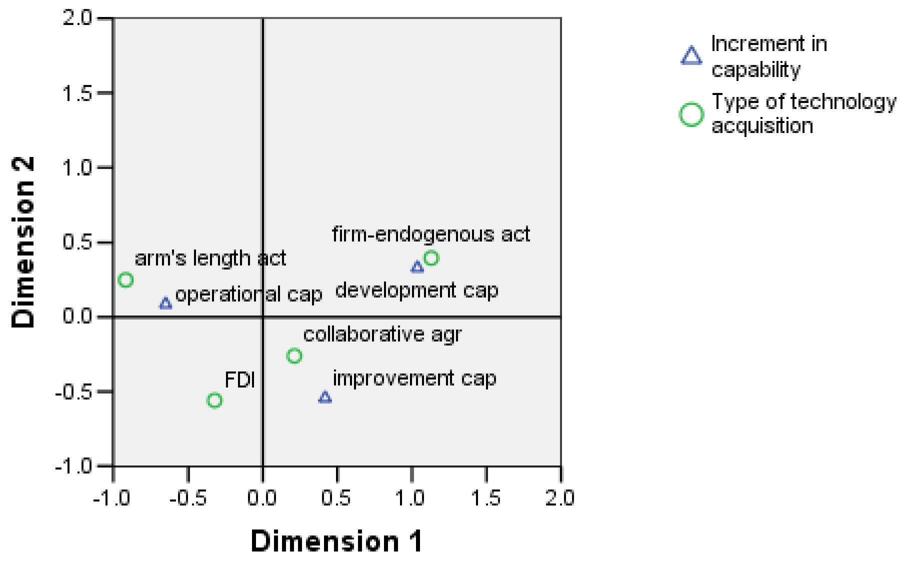
By inspection of Table 5.8, it appears that in both segments, proportion of links that resulted in increments in operational capabilities decreased, but the proportion of links resulting in increments in development capabilities increased over time. Nonetheless, as expected, firms in the science-based segment of the industry increased their acquisition of development capabilities during 1997-2001 by ***more*** than the mature technology firms (43.4% and 29.7%). They also managed to decrease their acquisition of operational capabilities from their knowledge links during the same sub-period by ***more*** than the mature technology firms (to 33.3% and to 47.4%, respectively).

In realising these changes over time, the second sub-period, from 1982 to 1996, acted as a transition period for both kinds of firms, during which intermediate capabilities such as technology improvement or imitation were incubated. This capability accumulation was then transmitted to product or process generation and innovation capabilities in the third sub-period. At first glance, these initial findings support Kim's (1999) postulate of three stages (emerging-intermediate-mature technology stages) being reversed in the case of developing countries' technological capability accumulation trajectory: acquisition to assimilation to improvement and then to development. Thus, it seems that the last five years of the analysis can be identified with emerging major changes in the two different segments of the Turkish materials industry. It was particularly the science-based technology firms that were showing early signs of moving to a different technological trajectory in the third sub-period of the analysis.

5.3.2 Increment in Capabilities and Modes of Technology Transfer

Figure 5.1, the correspondence analysis plot, shows that there is a close association between capability increment and the modes of technology transfer. It reveals that arm's length activities are associated closely with acquisition of increments in operational capabilities or no capability acquisition at all; firm-endogenous activities are associated closely with increments in development capabilities; and collaborative agreement modes of technology transfer are associated with those of improvement capabilities.

Figure 5.1 Correspondence analysis plot for increment in capability and mode of technology transfer for all firms (N=408)



In Table 5.9, drawn from Appendix tables C.28, C.29 and C.30, the Pearson chi-square test for INCCAP vs. TECHTRANS is significant at the 1% level when tested for all firms, indicating that the two variables are associated. This implies that the firms' levels of additional capabilities showed significant differences according to the ways they acquired their technologies. For all firms in the industry, the higher the level of additional capability acquired, the greater was the probability that they would have used their own in-house sources and would have collaborated with other firms or institutes in the industry. For instance, firms that had acquired only operational capabilities or no capabilities at all in their knowledge links were likely to use their own domestic sources for only about 5.6% of their knowledge links and they were likely to collaborate with other partners in about one-third of their links. For firms that had acquired capabilities for product or process development, these proportions were close to 50%.

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. TECHTRANS is significant at the 1% level for both types of firms, indicating that the two variables are associated in this context. This implies that for both science-based and mature technology firms, their levels of additional capabilities showed significant differences according to the ways they acquired their technologies. By inspection of Table 5.9, it appears that, in both segments, the higher the level of additional capability acquired, the greater was the probability that they would have used their own in-house sources and would have collaborated with other firms or institutes in the industry and the lower was the probability that they would have used arm's length relations. Even so, the science-based technology firms that had acquired only operational capabilities or none at all in their links were even ***less*** likely than mature technology firms to use their own in-house sources (3.0% and 7.8%) and ***much more*** likely to collaborate with other firms or institutes in the industry (43.6% and 29.6%).[51] If they had acquired development capabilities they were ***much more*** likely than mature technology firms to use their own in-house sources in these links (49.2% and 30.3%) and ***much less*** likely to collaborate with other partners (44.6% and 60.6%). Compared with the mature technology firms, firms in science-based industries that are building up their own technology development capabilities, were more likely to be able to acquire the technology they need from their own intra-firm capabilities – the reasons are elaborated in the next step of the analysis where the existing knowledge base and intensity of effort in the firms are examined. The mature segment of the industry relied heavily on other firms and institutes for technology development.

[51] For example, some of the science-based technology firms operating in the field of thin film ceramic coatings imported their process technologies – i.e. various versions of Physical Vapour Deposition (PVD) technique (see Appendix A.6.2.3). These firms found a remarkable way of forming close and continuous contacts with the nearby university departments of materials sciences. They employed engineers who were also doing their PhDs and MSc about PVD technique. At the initial stages, when these firms were accumulating operational capabilities, these engineers acted as means to transfer the knowledge from the university to the firm. Later on, firms built on this well-founded knowledge for accumulating their further higher-level capabilities.

Table 5.9 Firms' acquired incremental capabilities and the mode of technology transfer (percentage of links)

	The kinds of technology transfer											
Levels of additional capability acquired	For all firms [a]				For science-based technology firms [b]				For mature technology firms [c]			
	Arm's length activity	Firm endogenous activity	Collaborative agreements	Foreign direct investment	Arm's length activity	Firm endogenous activity	Collaborative agreements	Foreign direct investment	Arm's length activity	Firm endogenous activity	Collaborative agreements	Foreign direct investment
Operational capability or none	50.9	5.6	36.1	7.4	40.6	3.0	43.6	12.9	60.0	7.8	29.6	2.6
Capability for product or process improvement	14.9	23.4	54.3	7.4	17.6	11.8	58.8	11.8	11.6	37.2	48.8	2.3
Capability for product or process development	4.1	42.9	50.0	3.1	1.5	49.2	44.6	4.6	9.1	30.3	60.6	0.0
All	31.4	18.6	43.6	6.4	23.5	18.9	47.5	10.1	40.3	18.3	39.3	2.1
Pearson Chi-Square Tests for INCCAP vs. TECHTRANS (asymp. sig. 2-sided)	0.000				0.000				0.000			

a N=408, b N=217, c N=191.
Source: Author's interviews

5.3.3 Increment in Capabilities and the Existing Knowledge Base in the Firm: The Skilled Workforce

In Table 5.10, drawn from Appendix Tables C.31, C.32 and C.33, the Pearson chi-square test for INCCAP vs. PRES is significant at the 10% level when tested for all firms, indicating that the relationship between these two variables is suggestive but not conclusive. This implies that the firms' levels of additional capabilities might have shown differences according to the percentage of engineers/researchers in the firm. For all firms in the industry, the higher the level of additional capability acquired from the knowledge link, the greater was the probability that the percentage of researchers/ engineers in total employees of the firm would be more than 50%. For example, in firms that had acquired only operational capabilities or no capabilities at all, the share of researchers and engineers in total employees exceeding 50% was present in 8.8% of their knowledge links. In firms that had acquired product or process development capabilities, that proportion was 18.4%.

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. PRES is not significant for science-based technology firms, indicating that the two variables are not associated with differences in incremental capabilities, i.e. according to the percentage of researchers/engineers in the firm. On the other hand, the Pearson chi-square test for INCCAP vs. PRES is significant at the 5% level for mature technology firms, indicating that the two variables are associated in this case, again according to the percentage of engineers/researchers in the firm. By inspection of Table 5.10, it appears that the science-based technology firms involved similar proportions of researchers/engineers in the firm's projects regardless of the level of additional capability acquired from the knowledge link. If they had acquired only operational capabilities or none, in 14.9% of their knowledge links the percentage of researchers and engineers in total employees exceeded 50%. And, if they had acquired product or process development capabilities, that proportion was 20%. The result probably comes about because they deal with state-of-the-art process technologies and require skilled workforce at every level from operation to development. However, this difference was more noticeable in the mature segment of the industry (3.5% for operational capabilities and 15.2% for development capabilities). It is probable that the use of medium and low-technology products and processes did not necessitate the greater involvement of highly skilled people in the mature segment for increments in the operational capabilities, but it did if additional capabilities for development of a product or process were to be acquired.

Table 5.10 Firms' acquired capabilities and the percentage of researchers/engineers in total employees in firms (percentage of links)

	THE EXISTING KNOWLEDGE BASE IN THE FIRM: The percentage of researchers/engineers in total employees					
	For all firms [a]		For science-based technology firms [b]		For mature technology firms [c]	
Levels of additional capability acquired	≥ 50%	≤ 49%	≥ 50%	≤ 49%	≥ 50%	≤ 49%
Operational capability or none	8.8	91.2	14.9	85.1	3.5	96.5
Capability for product or process improvement	11.7	88.3	9.8	90.2	14.0	86.0
Capability for product or process development	18.4	81.6	20.0	80.0	15.2	84.8
All	11.8	88.2	15.2	84.8	7.9	92.1
Pearson Chi-Square Tests for INCCAP vs. PRES (asymp. sig. 2-sided)	0.051		0.313		0.021	

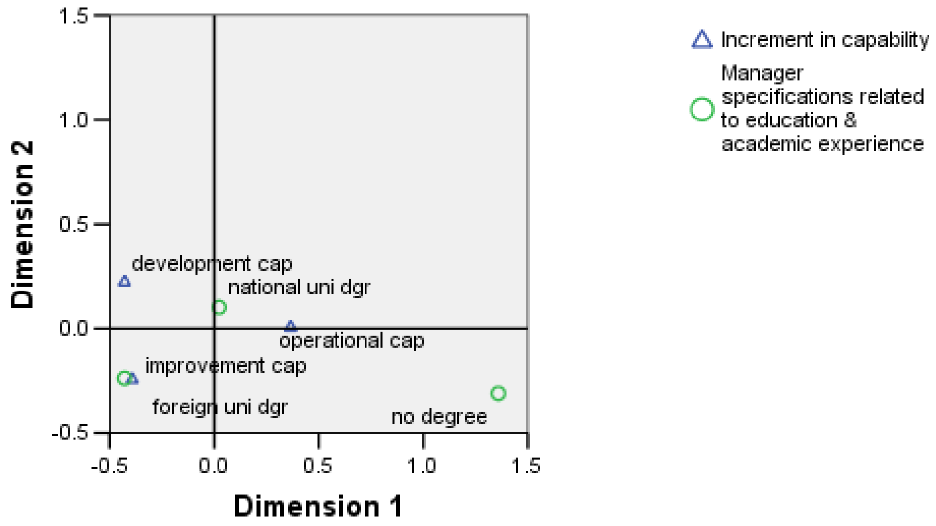
a N=408, *b* N=217, *c* N=191.
Source: Author's interviews

5.3.4 Increment in Capabilities and the Existing Knowledge Base in the Firm: Manager's Educational and Academic Endowments

Managerial skills related to academic and research experiences are categorised as having a degree from a university abroad or a degree from a domestic university or no degree in the activity field of the firm – i.e. an engineering degree. A 'degree' is adopted as an aggregated measure for a BSc, MSc and PhD.

Figure 5.2, the correspondence analysis plot, shows that there is an association between the levels of additional capability acquired from the knowledge links and the managers' educational and academic experiences. It suggests that managers with degrees from a foreign university are very closely associated with capability increments in technology improvement. However, it is not associated as closely to increments in development capability as would be expected. A degree from a national university is generally associated with increment in operational capability or no capability. Development capability stands alone on itself on the upper left quarter of the plot.

Figure 5.2 Correspondence analysis plot for increment in capability and manager specifications related to education and academic experience for all firms (N=408)



In Table 5.11, drawn from Appendix Tables C.34, C.35 and C.36, the Pearson chi-square test for INCCAP vs. MANACD is significant at the 5% level, indicating that the two variables are associated with each other. This implies that the firms' levels of additional capabilities showed differences regarding the academic skills of their managers. For all firms in the industry, the higher the level of additional capability acquired during the project, the greater was the probability that the manager would be overseas-trained. For example, firms that had acquired only operational capabilities or no capabilities at all were likely to be managed by managers with university degrees obtained abroad in about one fifth of their knowledge links. For firms that had acquired product or process development capabilities, that proportion was one in four. However, the proportion of links with managers holding an academic degree from domestic universities did not change significantly with the level of capability (72.2% for operational capabilities and 72.4% for development capabilities).

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. MANACD is significant at the 5% level for science-based technology firms, indicating that the two variables are associated in this context, implying that the science-based technology firms' levels of additional capabilities showed differences regarding the academic skills of their managers. On the other hand, the Pearson chi-square test for INCCAP vs. MANACD is not significant for mature technology firms, indicating that the two variables are not associated; hence their levels of additional capabilities did not show any differences according to the academic skills of their managers.

In Table 5.5, it appears that the mature technology firms mainly relied on home-trained managers at each level of additional capability acquired from the knowledge link. If they had acquired only operational capabilities or none, in 87.0% of their knowledge links, they had home-trained managers. If they acquired product or process improvement capabilities, this proportion was 90.7%, or 90.9% if they had acquired product or process development capabilities. This is probably because they deal with medium and low-tech product and process technologies and they do not necessarily require overseas-trained managers. However, this difference was more noticeable in the science-based segment of the industry for the proportions of links with overseas-trained managers (26.7% for operational capabilities, 43.1% for improvement capabilities and 33.8% for development capabilities). It is probable that the use of high-technology products and processes necessitates the greater involvement of overseas-training in the science-based segment for increments in improvement and development capabilities, and even in operational capabilities for use of sophisticated process technologies.[52]

Thus, managerial specifications related to academic experiences were related to increments in technological capabilities in the science-based segment of the industry only. It must be noted that when the manager's degree from a foreign university is broken down into BSc, MSc and PhD, it is seen that holding a PhD from abroad and

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[52] Complex products such as ultra-thin film ceramic coatings (on metal or glass substrates to further improve the structural and functional properties of end products (see Appendix A.5.2) which are generally used in cutting tool, machinery industries and biomedical applications) could only be produced using sophisticated techniques of Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD), ion implantation or sol-gel technology (see Appendix A.6.2). Operationalisation of these processes necessitate in-depth scientific education and training.

moreover having had further research experience at a university abroad did matter. Links conducted by managers with these qualifications acquired greater increments of technology development capabilities. However, having an MSc degree from a national university did not make a difference. Also, there were no managers with PhDs from national universities in the sample. Understandably, having had academic experience abroad added considerably to the prior knowledge of the firm. Kim (1998) underlines the importance of recruitment of researchers and engineers especially from the USA in

Table 5.11 Firms' acquired capabilities and the managerial specifications about academic experiences (percentage of links)

	THE EXISTING KNOWLEDGE BASE IN THE FIRM: Managerial specifications related to academic experiences								
	For all firms [a]			For science-based technology firms [b]			For mature technology firms [c]		
Levels of additional capability acquired	Foreign univ. degree	National univ. degree	No degree	Foreign univ. degree	National univ. degree	No degree	Foreign univ. degree	National univ. degree	No degree
Operational capability or none	19.0	72.2	8.8	26.7	55.4	17.8	12.2	87.0	0.9
Capability for product or process improvement	27.7	69.1	3.2	43.1	51.0	5.9	9.3	90.7	0.0
Capability for product or process development	25.5	72.4	2.0	33.8	63.1	3.1	9.1	90.9	0.0
All	22.5	71.6	5.9	32.7	56.7	10.6	11.0	88.5	0.5
Pearson Chi-Square Tests for INCCAP vs. MANACD (asymp. sig. 2-sided)		0.049			0.011			0.894	

a N=408, b N=217, c N=191.
Source: Author's interviews

Hyundai Motor's remarkable technology assimilation to innovation path. However, it is interesting to observe that in the science-based segment of the industry, the proportion of links with overseas-trained managers that resulted in increments in development capabilities (33.8%) was less than those that resulted in improvement capabilities

(43.1%). This also points to the fact that the science-based segment of the industry is in the stage of imitation.

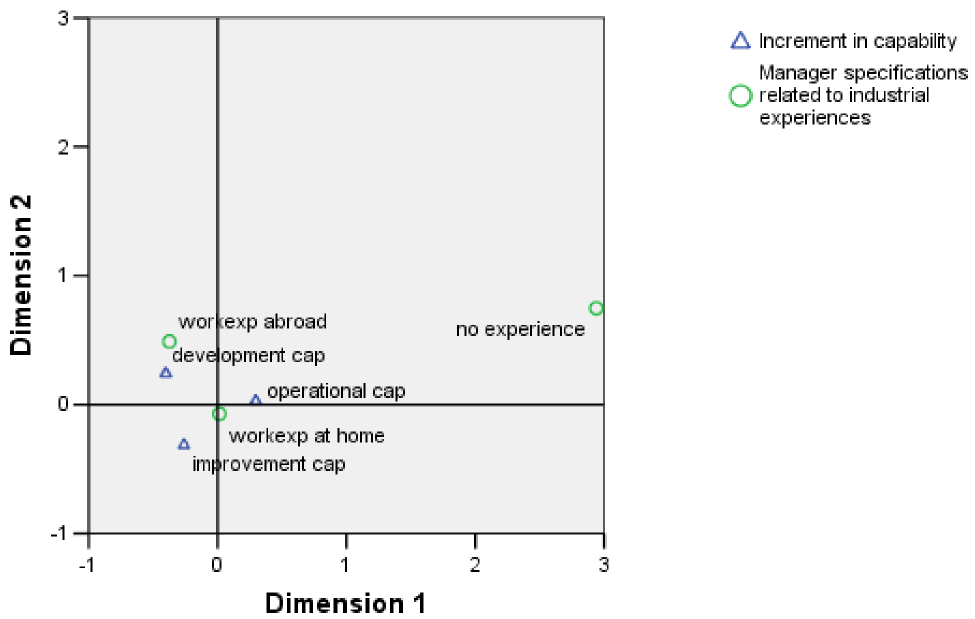
Finally, interestingly in the case of science-based technology firms, there were also a considerable number of links run by managers with ‘no academic degree’ related to the scientific field in which their firm was operating. 78% of the links managed by these kinds of managers resulted in increments in operational capability or no capability. An explanation to these cases is that, in manufacturing industries, firms often have managers with an engineering degree. However, there are also common cases of managers with degrees in business only. Among the science-based technology firms examined in this study, the majority firms were run by engineer-managers. Yet, there was also one science-based technology firm with a business-manager, who held a degree in marketing. This particular firm was founded as the sister firm of a mature parent firm. The employees of the parent firm appointed the manager for the new firm. Although there had been few engineers working in this firm, almost all of the technology projects conducted by the business-manager had been unsuccessful, whether simply the acquisition of a machine or a collaborative research project with a university. To compare, another science-based technology firm with an engineer-manager with research and work experience from abroad, however, was able to develop and build its own high technology production process, its own brand high technology products, etc. As Faulkner and Senker (1995: 112) observed in their study of engineering ceramics firms in the UK and US, it is generally the collective in-house teamwork activities in the firm that provide the most input to its scientific activities. Understandably, a manager with personally held knowledge in the field of activity plays a vital role for organising and co-ordinating in-house teamwork. Managers’ academic skills and experiences add to the firm’s absorption capability.

5.3.5 Increment in Capabilities and The Existing Knowledge Base in the Firm: Manager’s Industrial Experiences

Managerial skills related to industrial and work experience are categorised according to managers having work experience at a firm abroad or at a firm at home country or having no work experience before they took up their current post.

Figure 5.3, the correspondence analysis plot, shows that there may be some association between the levels of additional capability acquired from the knowledge links and the managers' industrial and work experiences. It suggests that managers with work experience abroad are associated with increments in technology development capabilities. Yet it does not say much about the relationship between work experience in a domestic firm and levels of capability increments.

Figure 5.3 Correspondence analysis plot for increment in capability and manager specifications related to industrial and work experience for all firms (N=408)



In Table 5.12, drawn from Appendix Tables C.37, C.38 and C.39, the Pearson chi-square tests for INCCAP vs. MANIND are not significant indicating that the two variables are not associated with each other. This suggests that the firms' levels of additional capabilities did not show any differences according to the industrial skills of their managers. Likewise, when controlled for the effects of the variable FIRMTYPE, the Pearson chi-square tests for INCCAP vs. MANIND remain not significant for both the science-based and the mature technology firms, again indicating that the two variables are not associated in this context. These results also suggest that neither the science-based nor the mature technology firms' levels of additional capabilities showed any differences according to the industrial skills of their managers. Thus, in neither segment would managers having had work experience abroad be influential in the acquisition of additional technological capability at any level.

Table 5.12 Firms' acquired capabilities and the managerial specifications about industrial experiences (percentage of links)

Levels of additional capability acquired	THE EXISTING KNOWLEDGE BASE IN THE FIRM: Managerial specifications related to industrial work experiences								
	For all firms [a]			For science-based technology firms [b]			For mature technology firms[c]		
	Work exp. abroad	Work exp. at home	No work exp.	Work exp. abroad	Work exp. at home	No work exp.	Work exp. abroad	Work exp. at home	No work exp.
Operational capability or none	10.2	88.0	1.9	17.8	78.2	4.0	3.5	96.5	0.0
Capability for product or process improvement	10.6	89.4	0.0	19.6	80.4	0.0	0.0	100.0	0.0
Capability for product or process development	14.3	85.7	0.0	21.5	78.5	0.0	0.0	100.0	0.0
All	11.3	87.7	1.0	19.4	78.8	1.8	2.1	97.9	0.0
Pearson Chi-Square Tests for INCCAP vs. MANIND (asymp. sig. 2-sided)	0.322			0.298			0.259		

a N=408, b N=217, c N=191.
Source: Author's interviews

However, the descriptive differences between the science-based and mature technology firms are worth mentioning. As apparent in Table 5.12, compared with mature technology firms, firms in the science-based industries were ***more*** likely to be managed by managers with work experiences abroad in about one fifth of their knowledge links regardless of whether they had acquired operational capabilities or product or process development capabilities in their knowledge links. These proportions were 3.5 % and 0.0% respectively in the mature technology firms. This finding shows that the science-based segment of the industry had some advantages regarding managers' industrial endowments over the mature segment.

5.3.6 Increment in Capabilities and the Intensity of Effort in the Firm: R&D Activities

R&D activities in firms are categorised in this research into 'primary R&D' conducted at the firm's own facilities, 'active R&D' conducted at the partner's facilities and 'no R&D' conducted in the firm.

Figure 5.4 Correspondence analysis plot for increment in capability and R&D activities for all firms (N=408)

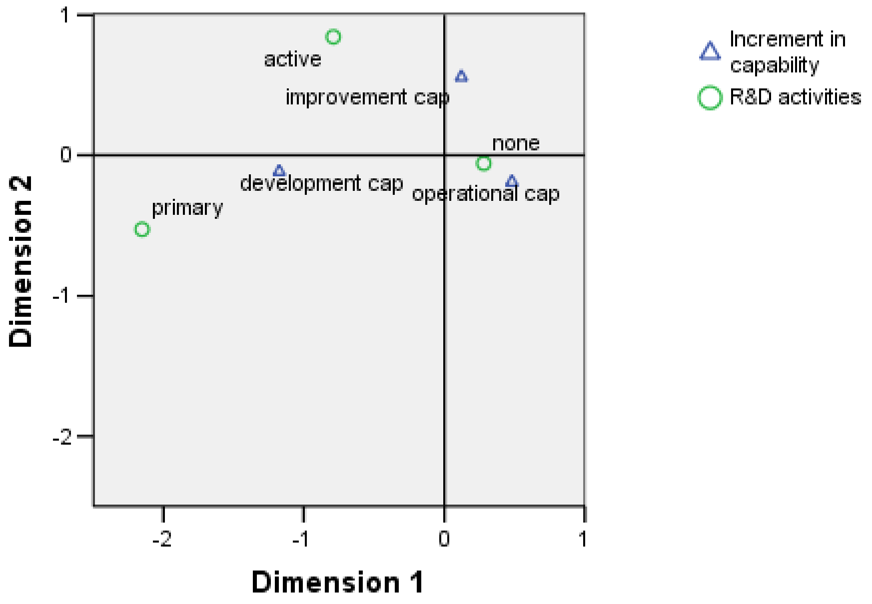


Figure 5.4, the correspondence analysis plot, shows that there is an association between the levels of additional capability acquired from knowledge links and the kinds of R&D conducted. It suggests that primary R&D activities are associated with increments in technology development capability and cases of no R&D conducted are closely

associated with increments in just operational capabilities or no capabilities acquired from knowledge links.

In Table 5.13, drawn from Appendix Tables C.40, C.41 and C.42, the Pearson chi-square test for INCCAP vs. RND is significant at the 1% level, indicating that the two variables are associated with each other. This implies that the firms' levels of additional capabilities showed differences regarding their efforts exerted in R&D activities. For all firms in the industry, the higher the level of additional capability acquired, the greater was the probability that they would have conducted primary R&D activities. For example, firms that had acquired only operational capabilities or none at all were likely to conduct primary R&D activities for as little as in 0.5% of their knowledge links. For firms that had acquired capabilities for product or process development, that proportion was 25.5%.

Controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. RND is significant at the 1% level for science-based technology firms and at the 5% level for mature technology firms, indicating that the two variables are associated in both contexts. This implies that for both the science-based and mature segment of the industry the firms' levels of additional capabilities showed significant differences regarding their R&D activities. By inspection of Table 5.13, it appears that in both segments the higher the level of capability acquired, the greater was the probability that both the science-based and mature segments of the industry would have conducted primary and active R&D activities in their technology projects. Even so, the science-based industries were much ahead of the mature industries in their use of primary R&D within the firm where necessary. The science-based technology firms that had acquired only operational capabilities or none in their knowledge links were ***not more*** likely than mature technology firms to conduct primary R&D (1.0% and 0.0%); but if they had acquired development capabilities they were considerably ***more*** likely than mature technology firms to conduct primary R&D[53] (35.4% and 6.1%). Active

[53] Primary R&D activities concentrate on both product and process development. In the science-based segment of the materials industry, product modification and development is closely related to improvements in the process technologies. For instance, as touched upon in Appendix A.6.2, slight modifications on techniques such as Physical Vapour Deposition (e.g. type of evaporation technique, range of vacuum pressure, range of vacuum temperature, arc current, etc.) make it possible for the process to be tailored for specific products with different properties to be coated on substrates such as metals and glass. Each of these variations potentially can result in improved or new products along with improved

R&D rates, where the firm conducted R&D in the university or research institute laboratories, were also higher in the science-based segment of the industry than the mature segment. This finding indeed captures most of what Kim (1998: 506) observed in Hyundai Motor's catching-up process as the 'imitative catching-up process' in the firm, as he identified as internal effort of the firm.

Table 5.13 Firms' acquired capabilities and R&D activities (percentage of links)

Levels of additional capability acquired	THE INTENSITY OF EFFORT IN THE FIRM: Kind of R&D activities in projects — For all firms [a]			For science-based technology firms [b]			For mature technology firms [c]		
	Primary	Active	None	Primary	Active	None	Primary	Active	None
Operational capability or none	0.5	4.6	94.9	1.0	5.9	93.1	0.0	3.5	96.5
Capability for product or process improvement	3.2	13.8	83.0	3.9	15.7	80.4	2.3	11.6	86.0
Capability for product or process development	25.5	18.4	56.1	35.4	21.5	43.1	6.1	12.1	81.8
All	7.1	10.0	82.8	12.0	12.9	75.1	1.6	6.8	91.6
Pearson Chi-Square Tests for INCCAP vs. RND (asymp. sig. 2-sided)	0.000			0.000			0.020		

a N=408, b N=217, c N=191.
Source: Author's interviews

5.3.7 Increment in Capabilities and The Intensity of Effort in the Firm: Design Activities

In Table 5.14, drawn from Appendix Tables C.43, C.44 and C.45, the Pearson chi-square test for INCCAP vs. DESIGN is significant at the 1% level, indicating that the

and slightly different processes – i.e. Cathodic Arc PVD, Electron Beam PVD, Magnetron Sputtering PVD or Plasma Enhanced PVD. Likewise, the production of composites needs continuous R&D activity in order to reliably align laminates or combine powders of different materials with different properties to obtain a final material with superior structural and functional properties (see Appendix A.5.2). This would necessitate a great amount of research activity about the selection, proper use, improvement and if necessary development of (new) raw materials (e.g. the kind of fibre used as the reinforcement material and the kind of binders and resins used as adhesives), as well as the choice of and improvements in processing techniques (see Appendix A.6.3).

two variables are associated with each other. This implies that the firms' levels of additional capabilities showed differences regarding their efforts exerted in design activities. For all firms in the industry, the higher the level of additional capability acquired, the greater was the probability that they would have conducted non-trivial design activities. For example, firms that had acquired only operational capabilities or none at all were likely to conduct non-trivial design activities for as little as in 6.5% of their knowledge links. For firms that had acquired capabilities for product or process development, that proportion was 69.4%.

Table 5.14 Firms' acquired capabilities and the level of design activities in firms (percentage of links)

	THE INTENSITY OF EFFORT IN THE FIRM: Level of design activities in projects					
	For all firms [a]		For science-based technology firms [b]		For mature technology firms [c]	
Levels of additional capability acquired	**Non-trivial**	**Trivial & none**	**Non-trivial**	**Trivial & none**	**Non-trivial**	**Trivial & none**
Operational capability or none	6.5	93.5	8.9	91.1	4.3	95.7
Capability for product or process improvement	35.1	64.9	29.4	70.6	41.9	58.1
Capability for product or process development	69.4	30.6	67.7	32.3	72.7	27.3
All	28.2	71.8	31.3	68.7	24.6	75.4
Pearson Chi-Square Tests for INCCAP vs. DESIGN (asymp. sig. 2-sided)	0.000		0.000		0.000	

a N=408, b N=217, c N=191.
Source: Author's interviews

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. DESIGN is significant at the 1% level for both science-based and mature technology firms, indicating that the two variables are associated in this context. This implies that both for science-based and mature technology firms the levels of additional capabilities showed significant differences in their design activities. By inspection of Table 5.14, it appears that in both segments the higher the level of additional capability acquired, the greater was the probability that both the science-based and mature segments of the industry would have conducted non-trivial design activities in their technology projects. The science-based technology firms that had acquired only operational capabilities or none in their knowledge links were a little ***more*** likely than mature technology firms to conduct non-trivial design activities (8.9% and 4.3%); and if they had acquired development capabilities they were a little ***less*** likely than mature technology firms to conduct non-trivial design activities (67.7% and 72.7%). This is probably because the science-based technology firms' design activities mostly concentrate on high technology design activities from product to process design, whereas mature technology firms' design activities mostly concentrate on medium level technology designs in parallel with their products and the mature processes they use. The main type of design activity in the mature segment of the industry is customer-guided design activities that largely rely upon customer recipes with little addition from firms. Conversely, in the science-based segment of the industry, the majority of the non-trivial design activities, which resulted in product or process development and improvement capabilities are the firms' own hi-tech design activities. These activities vary from original target design for ultra thin film ceramic coating processes to own polymer matrix composite design and fibre orientation design in fibre optics and high-tech process design in the industry.[54] The firms' own medium technology designs and customer-guided design activities also lead to capability increments in improvement and development of products or processes. Medium technology design activities range from original metal mould design to binder design for traditional ceramics or glass fibre, to original ceramic mould design and original powder characterization.[55]

[54] In the science-base segment of the industry, engineering firms, operating in the field of ultra thin film ceramic coatings, were continuously involved in developing composition (know-how) of different kinds of single layer and multi-layer coatings that provide the materials with different or more reliable properties, especially if they were opting to introduce improved or new products (see Appendix A.5.2.1). Such an activity concentrates on the design of raw materials such as compounds of titanium, zirconium, chromium, boron and tungsten (see Appendix A.6.2) to be placed on a target for ionisation in a vacuum chamber and to be deposited on a substrate (see Appendix A.6.2.3 and A.6.2.4). The design of a target for a titanium nitride (Ti_xN_y) coating with two elements would be relatively easier than the design of a target for a titanium carbonitride (TiC_xN_y) coating with an added third element. The successful design of a target would yield better results for thickness, hardness and adhesion of the coating. Similarly, design activities in the production of composite materials are based on improving product performance. Most depends on the fibre and whisker design, which involves the material selection, geometry and orientation, to be used with the appropriate material as the matrix (see Appendix A.5.3 and A.6.3).

[55] Especially for the firms operating in metal and ceramic parts production for automotive and cutting tools industries, design activities are predominantly concentrated on better performance of the products to meet customer demands. If the firm opts to rely on customer-guided designs, the recipes for powder mixtures for the products and all the drawings for product shape and tolerances are supplied by the client firms. Some firms also perform their own design activities, which are mould design and powder characterization. Such firms have a mould atelier for this aim endowed with lathes and CAD computer supported mould design. Moulds are placed in the dies of extrusion, wet and dry press and injection

Design activities particularly concentrated on product design in the materials industry. Science-based technology firms were engaged in complicated product design activities given the nature of their field of activity. Some of them even designed their high-technology production processes at the start-up of their firms.[56] These were the firms whose managers obtained their academic degrees abroad and had work experience abroad. The mature segment of the industry predominantly concentrated on customer-guided product design. Faulkner and Senker (1995: 106) also observed this kind of behaviour in some of the ceramics firms[57] in their sample from the UK and US. They interpreted firms' preference for low technology design activities by their lack of qualified researchers to carry out the design activities and also the concern among firms that their designs were easily copied and imitated by their rivals once the new design was introduced into the market. The former interpretation is largely valid for the mature segment of the Turkish materials industry. They do lack the skilled personnel endowed with design capabilities. The latter interpretation, however, is more valid for science-based technology firms. They had concerns about their designs being copied and imitated by their rivals; however, this concern did not stop them working on designing new products. Given the fact that their product designs are far too complicated, it is indeed rather difficult for a rival firm to copy a product and introduce it to the market before the original firm. Therefore, it is always the original firm to get its product a trademark or a patent and then others may work on this product as well, but that takes time.

5.3.8 Summary

Previously it was shown that technology acquisition characteristics in firms in the materials industry in Turkey shifted over time towards collaborative and intra-firm

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moulding machines to get the products with desired shapes and cross-sections. They are made of metals or hard ceramics. Successful powder characterization necessitates quantitative data on particle size and its distribution, particle shape and its variation with particle size, surface area, the internal particle friction, flow and packing, internal particle structure, chemical gradients, surface films, admixed materials regarding the powder (German, 1984: 10). Therefore, all of these parameters are important within the entire design activities, since the understanding of the powder leads to quality products (see Appendix A.6.1).

[56] These are process technologies such as MEVVA Metal Vapour Vacuum Arc Ion Beam Implantation System and derivatives of Physical Vapour Deposition (PVD) – i.e. Cathodic Arc PVD, Plasma Enhanced PVD and Magnetron Sputtering PVD, in ultra thin film ceramic coating field (see A.6.2.3).

[57] Faulkner and Senker's engineering ceramics firms produced technical ceramics parts by powder pressing techniques. Through the process technologies they used, they largely resemble to mature segment of the Turkish materials industry in this research.

relationships, in which skilled labour force and R&D and design activities were increasingly involved.

The second part of the analysis confirmed that firm level capabilities were strongly influenced by the existing knowledge base and particularly the intensity of effort of the firm and the mode of technology acquisition it chose. The higher the level of additional capability acquired, the greater was the probability that they would have used their own in-house sources and would have collaborated with other firms or institutes in the industry. Additionally, as firms' intensity of R&D and design activities increased, their acquisition of additional capability levels from the knowledge links tended to increase considerably. Characteristics such as the share of the skilled workforce and the managerial skills that identify the existing knowledge base in the firm showed differences by type of firm. In the science-based segment, as the level of the manager's academic skills increased, so did the level of additional capability acquired from links. In the mature segment of the industry, it was the ratio of researchers/engineers in the firm that was effective at the level of additional capabilities. The majority of these findings also overlap with Kim's findings in Korean industries.

The science-based segment of the industry appeared to be better endowed than the mature segment of the industry in terms of skilled workforce and managerial experience. Following from these, the strong base of existing knowledge in the firm allowed the science-based technology firms to behave more aggressively in R&D and design activities and conduct their own intra-firm technology projects with support from knowledgeable outside partners, especially within the last five years studied here. Consequently, they had a larger proportion of knowledge links that yielded higher levels of capability acquisition compared to the mature segment of the industry.

5.4 Econometric Analyses

This section first describes the three sets of multinomial logistic regression models built to assess technology transfer and its influences on increments of technological capability at the firm level. Then it analyses the results obtained from these regressions.

Multinomial logistic regression models were first presented in Chapter 3. They can be used to assess the effects of the elements of technology transfer on the accumulation of firm-level technological capabilities. As different from cross-tabulation analysis, multinomial logistic regression allows the researcher to comment on the strength and direction of the relationships between the dependent variable and the full set of explanatory variables.

As previously discussed in the Methodology Chapter, technology transfer is explained by the mode of technology transfer, existing knowledge base of the firm and intensity of effort in the firm. Therefore, three individual models are set up to capture the effect of each element on capability increments. A dummy variable representing science-based technology firms is used in each model[58].

5.4.1 Multinomial Logistic Regression Models

On the basis of the variables described in section 3.7 above, the log risk-ratio[59] equations were specified as Equation 5.1, Equation 5.2 and Equation 5.3. In the equations, the category $j = 1$ – that is, increment in capability being in the process operation or no capability acquired category – is referred to as the 'base category' for the dependent variable. Therefore, the coefficients of this category are set to zero and the risk-ratios of the other categories are defined with respect to the probability of this base category. Any of the categories of the dependent variable could be chosen as the base category. In this analysis, with 'capability increments in process operation or no capability acquired' category being selected as the base category, the risk-ratios of the other two outcomes – increments in process or product improvement capability and increments in process or product development capability – are as stated defined with respect to the probability of this base outcome.

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[58] Even though initially several models were constructed with a period variable, in the end this variable is not introduced in the multinomial logistic regression models. The use of a period variable would necessitate omitting interaction variables in the models (e.g. PRES*DFIRM, DESIGN*DFIRM, etc.), since the limitations of the database caused problems in the regressions. Because section 5.3.1 already deals with the association between INCCAP and PERIOD in Table 5.8, it is considered that excluding the period variable from the econometric analyses would not cause a major deficiency in the overall analyses.

[59] As previously stated in section 3.7.2, a *risk-ratio* is the ratio of the probability of outcome *m* to that of outcome *k*, or $[Prob(Y_i = m) / Prob(Y_i = k)]$. For the models set up in this research, the first risk-ratio is the ratio of the probability of a capability increment in improvement of a product or process to the probability of capability increment in process operation. The second risk-ratio is the ratio of the probability of capability increment in development of a product or process to the probability of capability increment in process operation.

Model 5.1: Increment in Capability and Modes of Technology Transfer

The first model assesses the effect of technology transfer mode on capability increments:

Equation 5.1

$$\text{Log}\ [\Pr(INCCAP=j)/\Pr(INCCAP=1)] = \alpha_0 + \alpha_1 TECHTRANS + \alpha_2 DFIRM + \alpha_3 TECHTRANS*DFIRM + \varepsilon_{ij}$$

where INCCAP=increment in capability
TECHTRANS= mode of technology transfer
DFIRM= dummy for science-based technology firm

Multinomial logistic regression estimates from equation 5.1 would look as follows:[60]

Equation 5.1a

$$\text{Log}\ [\Pr(INCCAP=\text{improvement of technology})/\Pr(INCCAP=\text{operation of technology or no capability})] = \alpha_0 + \alpha_{11} TECHTRANS_{armlength} + \alpha_{12} TECHTRANS_{firmendogenous} + \alpha_{13} TECHTRANS_{collaborativeagr} + \alpha_2 DFIRM_{sciencebased} + u$$

Equation 5.1b

$$\text{Log}\ [\Pr(INCCAP=\text{development of technology})/\Pr(INCCAP=\text{operation of technology or no capability})] = \beta_0 + \beta_{11} TECHTRANS_{armlength} + \beta_{12} TECHTRANS_{firmendogenous} + \beta_{13} TECHTRANS_{collaborativeagr} + \beta_2 DFIRM_{sciencebased} + u$$

Model 5.2: Increment in Capability and Existing Knowledge Base in the Firm

The second model assesses the effect of existing knowledge base of the firm on capability increments:

Equation 5. 2

$$\text{Log}\ [\Pr(INCCAP=j)/\Pr(INCCAP=1)] = \beta_0 + \beta_1 PRES + \beta_2 MANACD + \beta_3 MANIND + \beta_4 DFIRM + \beta_5 PRES*DFIRM + \beta_6 MANACD*DFIRM + \beta_7 MANIND*DFIRM + \varepsilon_{ij}$$

where INCCAP=increment in capability
PRES=percentage of researchers/engineers to total employees in the firm
MANACD=manager specifications related to academic and research experience

[60] The interaction variable TECHTRANS*DFIRM has been omitted from the model by the author, because the regression analysis encountered warnings about the unexpected singularities in the Hessian matrix, which required the exclusion of some explanatory variables.

MANIND= manager specifications related to industrial and work experience
DFIRM= dummy for science-based technology firm

Multinomial logistic regression estimates from equation 5.2 would look as follows:[61]

Equation 5.2a

Log [Pr(INCCAP=improvement of technology)/Pr(INCCAP=operation of technology or no capability)] = $\alpha_0 + \alpha_{11}PRES_{morethan50} + \alpha_{21}MANACD_{foreigndgr}$
$+ \alpha_{22}MANACD_{nationaldgr} + + \alpha_4 DFIRM_{sciencebased}$
$+ \alpha_5 PRES_{morethan50} * DFIRM_{sciencebased} + u$

Equation 5.2b

Log [Pr(INCCAP=development of technology)/Pr(INCCAP=operation of technology or no capability)] = $\beta_0 + \beta_{11}PRES_{morethan50} + \beta_{21}MANACD_{foreigndgr}$
$+ \beta_{22}MANACD_{nationaldgr} + \beta_4 DFIRM_{sciencebased}$
$+ \beta_5 PRES_{morethan50} * DFIRM_{sciencebased} + u$

Model 5.3: Increment in Capability and Intensity of Effort in the Firm

The third model assesses the effect of intensity of effort of the firm on capability increments:

Equation 5.3

Log [Pr(INCCAP=j)/Pr(INCCAP=1)] = $\delta_0 + \delta_1 RND + \delta_2 DESIGN + \delta_3 DFIRM$
$+ \delta_4 RND*DFIRM + \delta_5 DESIGN*DFIRM + \varepsilon_{ij}$

where INCCAP=increment in capability
RND=R&D activities
DESIGN=design activities
DFIRM= dummy for science-based technology firm

Multinomial logistic regression estimates from equation 5.3 would look as follows:[62]

Equation 5.3a

Log [Pr(INCCAP=improvement of technology)/Pr(INCCAP=operation of technology or no capability)] = $\alpha_0 + \alpha_{11}RND_{primary} + \alpha_{12}RND_{active} + \alpha_2 DESIGN_{nontrivial}$
$+ \alpha_3 DFIRM_{sciencebased} + \alpha_4 DESIGN_{nontrivial} * DFIRM_{sciencebased} + u$

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[61] The variable MANIND has been omitted from the model by the author, because the regression analysis encountered warnings about the unexpected singularities in the Hessian matrix, which required the exclusion of some explanatory variables. This was an expected outcome, since the bivariate chi-square test for INCCAP and MANIND, given previously in section 5.3.5, also indicated that the relationship between these two variables was statistically insignificant Afterwards, the interaction variable MANACD*DFIRM was omitted from the model by the stepwise method of backward elimination.

[62] The interaction variable RND*DFIRM was omitted from the model by the stepwise method of backward elimination.

Equation 5.3b

Log [Pr(INCCAP=development of technology)/Pr(INCCAP=operation of technology or no capability)] = $\beta_0 + \beta_{11}RND_{primary} + \beta_{12}RND_{active} + \beta_2 DESIGN_{nontrivial} + \beta_3 DFIRM_{sciencebased} + \beta_4 DESIGN_{nontrivial} * DFIRM_{sciencebased} + u$

5.4.2 The Estimates

All the regressions were run considering the full models and the restricted models – i.e. when the insignificant variables that do not contribute to the model are automatically omitted from the full model. The full model always included stepwise terms showing the interactive effect of two explanatory variables on the dependent variable – i.e. TECHTRANS*DFIRM, RND*DFIRM, etc. To obtain the restricted models, the backward elimination method was applied to custom-specified models as the stepwise method wherever possible. However, in some cases the backward elimination method did not prove to be useful, since it brought with it problems encountered in the Hessian matrix. Then, elimination of the insignificant variable(s) had to be done manually.

The full specification model was not preferred for two reasons. First, when the full specification was confronted with the data, it was found that these variables did not exert a significant effect on the risk-ratios. Second, the validities of multinomial logistic regression models with full specification were uncertain because of problems encountered in the Hessian matrix (problems of singularity linked to multicollinearity). The goodness-of-fit value for the model (Chi-square test and the significance value) was not statistically significant. That is why, either the backward elimination method or direct elimination of insignificant variables is utilised to assess the effects of the significant variables in the models.

As with any fitted model, before making inferences, the overall fit of the model should be assessed; however in multinomial logistic regression this is a difficult problem since there are multiple outcome categories and the integrated assessment of fit for the two logits need to be considered (Hosmer and Lemeshow, 2000: 281). The 'goodness-of-fit' measures for the models are shown below each results table. These include the log-likelihood measure as a minimum measure to be stated as suggested by Greene (2000: 831-833), chi-square measure, significance value of the chi-square measure and

McFadden's Pseudo R^2 value. As Borooah (2002: 57) points out the Pseudo R^2 is due to McFadden (1973) and is bounded from below by 0 and from above by 1. A value of 1 corresponds to perfect prediction of the model. However, as Greene (2000) notes "the values between 0 and 1 have no natural interpretation, though it has been suggested that the Pseudo R^2 value increases as the fit of the model improves."

5.4.2.1 Mode of Technology Transfer and Increment in Capabilities

Equation 5.1 is used to assess the effect of technology transfer mode on capability increments. The model is statistically significant at the 1% level, which shows that the included explanatory variables have significant explanatory power on the log risk-ratios.

The estimation results, displayed in Table 5.15, identify two characteristics as being important for improving a link's risk-ratio of yielding capability increments particularly in development of a product or process:

- Engaging in firm-endogenous activity and collaborative agreement modes of technology transfer regarding both kinds of firms; and also
- Being a science-based technology firm.

The risk-ratio of firms having capability increments in improvement and development of a product or process from links with the firm-endogenous activity and collaborative agreement modes of technology transfer was *ceteris paribus* higher than that of links with foreign direct investment (FDI)[63]. The risk-ratio of a link resulting in capability increments in improvement and development of technology was greatest for the firm-endogenous mode of technology transfer (α_{12} and $\beta_{12}>0$ in Eqn.5.1a and 5.1b). Also, a link based on firm-endogenous activity could result in more capability increment for the development of product or process compared to that for the improvement of product or process ($\beta_{12}>\alpha_{12}$). However, the risk-ratio of firms having capability increments in improvement from links with the arm's length mode of technology transfer was *ceteris paribus* lower than that of links with FDI ($\alpha_{11}<0$ in Eqn.5.1a).

[63] Except for the links with the collaborative agreement mode of technology transfer and their effect on capability increments particularly on the improvement of a product or process. In this case, the variable is statistically insignificant.

Table 5.15 Results of multinomial logistic regression for Model 5.1 (restricted specification by backward elimination method)

Logit	Variables	Coeff.	Std. Err.	Wald (z)	Sig. P>|z|
Equation 5.1a	Constant	-1.009	0.508	3.941	0.047**
	TECHTRANS= Arm's length activity	-1.124	0.547	4.233	0.040**
	TECHTRANS= Firm endogenous activity	1.520	0.589	6.659	0.010***
	TECHTRANS= Collaborative agreements	0.444	0.495	0.805	0.370
	DFIRM= Science-based technology firm	0.217	0.271	0.639	0.424
Equation 5.1b	Constant	-2.384	0.686	12.087	0.001***
	TECHTRANS= Arm's length activity	-1.310	0.817	2.571	0.109
	TECHTRANS= Firm endogenous activity	3.221	0.723	19.829	0.000***
	TECHTRANS= Collaborative agreements	1.405	0.662	4.503	0.034**
	DFIRM= Science-based technology firm	0.811	0.298	7.387	0.007***

Log-likelihood=-139.112; Chi-square=134.211; sig.=0.000; PseudoR^2(McFadden)=0.162; N=408
Omitted variable: TECHTRANS*DFIRM.
***Statistically significant at 1%, **Statistically significant at 5%.

As complementary to the kinds of technology transfer, the type of firm also matters for capability increments in product or process development. The probability of having capability increments in the development of technology to that of process operation was *ceteris paribus* higher in science-based technology firms than in mature technology firms ($\beta_2 > 0$ in Eqn. 5.1b). The 'firm type' effect proved to be statistically insignificant for the probability of having capability increments in improvement of technology exceeding those of process operation.

5.4.2.2 Existing Knowledge Base of the Firm and Increment in Capabilities

Equation 5.2 is used to assess the effect of existing knowledge base in the firm on capability increments. The model is statistically significant at the 1% level, which shows that the explanatory variables have significant explanatory power on the log risk-ratios.

The estimation results, displayed in Table 5.16, identify two characteristics as being important for improving a link's risk-ratio of yielding capability increments both for improvement and development of a product or process:

- Being endowed with researchers and engineers in the firm as more than 50 per cent of the total employees and also with managers holding academic degrees related to the activity field of the firm regarding both kinds of firms; and also
- Being a science-based technology firm.

The risk-ratio of firms having capability increments in improvement and development of technology from links at the time when the firm had a ratio of researchers and engineers of more than 50% in total employees was *ceteris paribus* higher than when the firm's ratio of researchers and engineers was under 49%. Similarly, the risk-ratio of firms having capability increments in improvement and development of technology from links conducted by managers with academic degrees related to the field of activity of the firm was *ceteris paribus* higher than that of links conducted by managers with no academic degrees related to the firm's field of activity.

A degree obtained abroad raised the risk-ratio of achieving capability increments for technology improvement just a little more than a degree obtained from the home country ($\alpha_{21}>\alpha_{22}$ in Eqn. 5.2a). From the previous analyses, it is known that managers with degrees from abroad were mostly specific to science-based technology firms. Although it has been anticipated that these kind of managerial qualifications would add largely to firms' innovative capabilities, it did not happen so in the science-based segment of the Turkish materials industry. Instead, their influence was almost the same on technology improvement capabilities mostly associated with imitation and small-scale developments as on technology development capabilities associated with innovation. This may be mainly because science-based firms had been dealing with significantly complex and novel processes and products and these technologies need precise and deep knowledge for radical innovations to occur.[64] These kinds of innovations rarely take place in a catching-up country. Thus, along with the level of

[64] Process development activities have taken place in some of the science-based technology firms at the start of their lifetime regarding sophisticated processes such as slightly different versions of Physical Vapour Deposition (PVD) and ion implantation and their related ultra thin film ceramic coating products such as titanium nitride, titanium carbonitride, zirconium nitride, chromium nitride, titanium zirconium nitride, etc. (see Appendix A.6.2). Some other sophisticated processes such as injection moulding for the production of small technical ceramic parts like insulators, honeycomb strainers for metal casting, catalytic convertors, ceramic ferrites and piezoelectrics used in electric electronic industry, oxygen sensors for the steel industry and resin transfer moulding (RTM) for production of polymer matrix composites that are used in aircraft and defence industries have often been subject to incremental improvements (see Appendix A.6.3 and Section 4.3 in Chapter 4).

prior knowledge they have, managers and scientists in science-based technology firms could yield better results regarding the accumulation of their capabilities on technology improvement and assimilation of complex technologies.

Table 5.16 Results of multinomial logistic regression for Model 5.2 (restricted specification by backward elimination method)

Logit	Variable	Coeff.	Std. Err.	Wald (*z*)	Sig. P>|*z*|
Equation 5.2a	Constant	-2.384	0.677	12.406	0.000***
	PRES=researchers more than 50%	1.586	0.675	5.519	0.019**
	MANACD=degree from university abroad	1.826	0.695	6.908	0.009***
	MANACD=degree from national university	1.204	0.657	3.361	0.067*
	DFIRM= Science-based technology firm	0.559	0.276	4.093	0.043**
	PRES(>50%)*DFIRM(science-based firm)	-2.685	0.920	8.575	0.004***
Equation 5.2b	Constant	-3.300	0.795	17.240	0.000***
	PRES=researchers more than 50%	1.579	0.704	5.026	0.025**
	MANACD=degree from university abroad	1.799	0.828	4.724	0.030**
	MANACD=degree from national university	1.944	0.770	6.373	0.012**
	DFIRM= Science-based technology firm	1.080	0.284	14.414	0.000***
	PRES(>50%)*DFIRM(science-based firm)	-1.302	0.892	2.129	0.145

Log-likelihood=-110.31; Chi-square=37.013; sig.=0.000; PseudoR^2(McFadden)=0.045; N=408
Omitted variables: MANIND, MANIND*DFIRM, MANACD*DFIRM.
***Statistically significant at 1%. **Statistically significant at 5%. *Statistically significant at 10%.

A degree for managers obtained at home raised the risk-ratio of achieving capability increments in technology development more than a degree obtained abroad ($\beta_{21}<\beta_{22}$ in Eqn. 5.2b). Almost 75% of all links are directed by managers with academic degrees from national universities. The majority of these managers seemed quite enthusiastic about the work they did. Their activities were largely concentrated on low and medium level mature technologies. Since these kinds of processes and products have been on the market for a long time, it is rather easier to imitate and improve such technologies in the form of development for many firms.[65]

[65] These processes mainly were relatively simple cold or hot pressing, isostatic pressing methods and the thermal treatment processes such as sintering by which small particles of material are bonded together in solid state diffusion (see Appendix A.6). These are used for the production of small metal parts by pressing metal powders to produce low, medium and high density products mainly for the automotive

The type of firm mattered for capability increments in both improvement and development of technology. The risk-ratios of having capability increments in improvement and development of technology were *ceteris paribus* higher in science-based technology firms than in mature technology firms (α_4>0 in Eqn. 5.2a and β_4>0 in Eqn. 5.2b). Whatever the observations above about the indicators of prior knowledge base in the firm, the 'firm type' effect proved to be in favour of science-based segment of the industry, particularly regarding development capabilities.

Finally, the reduction in the risk-ratio of being involved in technology improvement for a firm with researchers/engineers exceeding 50% of its total employees at the time of the link is greater for a science-based technology firm than for a mature firm. Even though the use of higher percentages of researchers is likely to improve the capability outcomes from a link, it may not be so clear-cut in the case of a science-based technology firm in a developing country. This can be explained by the risk factors involved in high technology activities in the science-based segment of the industry, as mentioned in the earlier cross-tabulation analysis.

5.4.2.3 Intensity of Effort in the Firm and Increment in Capabilities

Equation 5.3 is used to assess the effect of intensity of effort in the firm on capability increments. The model is statistically significant at 1% level, which shows that the explanatory variables have significant explanatory power on the log risk-ratios.

The estimation results displayed in Table 5.17 identify one characteristic as being important for improving a link's risk-ratio of yielding capability increments in both the improvement and development of a product or process:

- Being involved in primary and active R&D activities and non-trivial design activities, regarding both kinds of firms.

The risk-ratio of firms having capability increments particularly in the development of technology from links with primary and active R&D was *ceteris paribus* higher than for

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industry such as filters, bearings, shock absorber pistons, gears, seal parts, alternators, friction discs, etc. (see Section 4.3 in Chapter 4). Many mature technology firms were able to reproduce such kind of technologies and even add improvements on the new machines compared to the existing machines.

links without any R&D activity. Primary R&D was not statistically significant for capability increment in technology improvement.

Similarly, the risk-ratio of firms having capability increments in improvement and development of technology from links with non-trivial design activities was *ceteris paribus* higher than for links with trivial design or no design activity. Actually, the risk-ratio of a link resulting in capability increments in development of technology was the greatest for non-trivial design activities ($\beta_2 > 0$ and $\beta_2 > \beta_{11}, \beta_{12}, \beta_3, \beta_4$ in Eqn.5.3b). In the materials sector, new designs pave the way for new products. Therefore, design capability is substantial.

Table 5.17 Results of multinomial logistic regression for Model 5.3 (restricted specification by backward elimination method)

Logit	Variable	Coeff.	Std. Err.	Wald (*z*)	Sig. P>|*z*|
Equation 5.3a	Constant	-1.525	0.224	46.422	0.000***
	RND=primary	1.451	1.189	1.489	0.222
	RND=active	0.896	0.471	3.625	0.057*
	DESIGN=non-trivial	2.702	0.554	23.795	0.000***
	DFIRM(science-based technology firm)	0.491	0.299	2.702	0.100
	DESIGN(non-trivial)*DFIRM(science-based firm)	-1.455	0.728	3.995	0.046**
Equation 5.3b	Constant	-2.574	0.350	54.116	0.000***
	RND=primary	3.384	1.079	9.842	0.002***
	RND=active	1.231	0.494	6.213	0.013**
	DESIGN=non-trivial	3.885	0.608	40.814	0.000***
	DFIRM(science-based technology firm)	0.809	0.433	3.487	0.062*
	DESIGN(non-trivial)*DFIRM(science-based firm)	-1.403	0.766	3.352	0.067*

Log-likelihood=-131.008; Chi-square=178.847; sig.=0.000; PseudoR^2(McFadden)=0.215; N=408
Omitted variable: RND*DFIRM.
***Statistically significant at 1%. **Statistically significant at 5%. *Statistically significant at 10%.

The 'firm type effect' was significant only at the 10% level in favour of science-based technology firms regarding an increase in the risk-ratio of a link yielding capability increment in technology development. This indicates that the intensity of effort, which is comprised of mainly primary R&D activities and non-trivial design activities, exerted to achieve increment in technology development capability is largely associated with the science-based segment of the industry.

Finally, the reduction in the risk-ratio of being involved in technology improvement and development for a firm engaged in non-trivial design activities was greater for a science-based technology firm than a mature firm. This can be explained by the risk factors involved in high technology design activities of complex products and processes in science-based technology firms. Mature firms get engaged in low technology design activities, which often guarantee a satisfactory and successful outcome.

5.4.3 Summary

The results from the multinomial logistic regression analyses are consistent with the earlier findings from the cross-tabulation analyses. They also confirm that firm-level capabilities were strongly influenced by the existing knowledge base and intensity of effort in the firm as well as the kind of technology transfer it chose. This influence was found to be stronger in the science-based segment of the industry than the mature segment. In addition to these, multinomial logistic regressions reported that the probability of acquiring development capabilities was greater than that of improvement capabilities for the science-based segment of the industry and if the firms opted for intra-firm and collaborative agreement kinds of technology transfer. Even though the probability of acquiring development capabilities was not different from that of improvement capabilities if the firms had high levels of the existing knowledge base (i.e. researchers-engineers as more than 50% of the employees, managers with academic degrees from universities abroad or at least from national universities), the probability of acquiring development capabilities was greater than that of improvement capabilities for the science-based segment of the industry and if the firms had high levels of the intensity of effort (i.e. they invested heavily in primary and active R&D and design activities).

5.5 Conclusions

As highlighted in the summary sections throughout this chapter, the analysis of the firms in the materials industry in Turkey shows that firm-level capabilities were increasing over time during the period 1967 to 2001. They were also increasing over time with the increasing level of absorptive capacity in the firm and firm's involvement in the collaborative agreement mode of technology transfer and own in-firm activities. Both the cross-tabulation analyses and the multinomial logistic regression analyses found that the effect of absorptive capacity and technology transfer processes on technological capability increments was greater in the science-based segment of the industry. This was because the science-based technology firms were better endowed firstly by means of the existing knowledge base in the firm – i.e. researchers and managers' academic experiences which would expected to be positively elevating the level of R&D and design activities in these firms and in turn influencing the increments in technological capabilities. Therefore, the strong base of existing knowledge in the firm allowed the science-based technology firms to behave more aggressively in R&D and design activities and conduct their own intra-firm technology projects with support from knowledgeable outside partners, especially within the last five years in this study. Consequently, they had a greater proportion of knowledge links that yielded higher levels of capability acquisition compared to that of the mature segment of the industry. In Kim's (1997: 97) words, 'one of the important elements of effective knowledge conversions leading to productive learning in the firm, the existing knowledge base, of course mostly tacit knowledge', appeared to be playing a more crucial role in the science-based technology firms.

Although to a less extent than for science-based technology firms, efforts of the mature segment of the industry cannot be undermined. They obviously had disadvantages over managerial aspects, proportion of researchers, ongoing research activities within the firm. However, particularly within the last five years studied here, they invested heavily in novel process technologies in their field in the form of import of machinery and became more conscious about what to ask from their technology suppliers in the form of training they received for their personnel on how to use the machines and even about troubleshooting. In addition, they approached domestic universities to complement their lack of knowledge in process operation and troubleshooting. These kinds of assistance paved the way for joint technology projects for process imitation in many firms and even towards cost-cutting minor and major novel improvements in already existing processes. This boosted the confidence levels of mature technology firms.

Having found that firm level capabilities were deepening over time in the materials industry in Turkey, the next chapter will look into the interactions of these firms over the time period of 1967 to 2001.

CHAPTER 6 TECHNOLOGICAL CAPABILITIES AND THE EMERGENCE OF INNOVATION SYSTEMS

6.1 Introduction

In the preceding Chapter 5, the impact of technology acquisition process on the development of technological capabilities in the firm was analysed. The core of this chapter is the ways in which the accumulation of technological capabilities in firms paves the way for the emergence of an innovation system in the materials industry during the period from 1967 to 2001 in Turkey. It aims to answer the research question:

"How do the technological capabilities from the technology transfer process influence the emergence and the elements of the system of innovation in the materials industry in Turkey?"

In section 3.6.2 of Chapter 3, the aspects of an innovation system were introduced as drawn from the literature. These are stated as: domestic and foreign links to characterize the origin of knowledge in the innovation system; institutional and inter-firm links and intra-firm sources to represent the sources of knowledge in the system; and density of the system to identify how vibrant it is.

In this chapter, the influence of firm-level technological capability accumulation on the emergence of an innovation system is evaluated. For parts of this analysis, the primary dataset comprising 408 observations, which has been used in the capability analysis in Chapter 5, is used. As was explained in Section 3.4.7, each of the 408 observations in the primary dataset actually represents a knowledge link, which is attached to a particular technology project, between the firm and any one of the partners in the system of innovation including their own sources. For other parts of this analysis, the primary dataset is transformed into a new dataset.

This chapter is designed in four parts. Section 6.2 presents the dataset, frequencies of the variable categories in the dataset, and the changes over time regarding these variable categories. Section 6.3 deals with the cross-classification analyses of the dependent and the explanatory variables, except the density of links variable. Because the latter variable does not have a matching observation for each link, it is not possible to apply cross-tabulation analysis for this variable and increments in capabilities, searching for causality. Instead, in section 6.2.3 some descriptive statistics are provided for the density of links variable. Section 6.4 presents the linear regression models and the results obtained from these econometric analyses. Finally, Section 6.5 concludes.

6.2 Structure of the Innovation System in the Materials Industry in Turkey

This descriptive section aims to present the data related to system characteristics gathered in face-to-face interviews in the firms. It mainly focuses on the frequencies of categories of the variables. In doing this, as well as the industry in general, the distinction between two different segments of the industry – i.e. science-based technology and mature technology – is highlighted.

Frequencies of knowledge links pertaining to the categories of variables are presented in this section for all firms and compared across science-based and mature technology firms in Tables 6.1 to 6.8. The key properties of the system have been previously identified as origin of knowledge, types of source of knowledge and density of links. ‘Origin of link’, ‘type of source’ and ‘density of links’ stand for the dependent variables of the analysis in this section. ‘Increment in capability’ represents the explanatory variable. The variables tested here are described in detail in Section 3.6.2 above.

The database that is used in this section is the main dataset formed by 408 observations for links derived from face-to-face interviews in the sample firms. Results of non-parametric chi-square statistics are also provided for the contingency tables. Simple frequency analysis is followed by a dynamic analysis in Section 6.2.4, to trace changes over time in the structure of the innovation system.

6.2.1 Origin of Knowledge Link

The origin of knowledge link, i.e. whether it is foreign or domestic, is identified as a system characteristic in the analysis. Table 6.1 suggests that, from 1967 to 2001, firms in the materials industry in Turkey were ***more*** likely to use foreign sources of knowledge than domestic sources (57.1% and 42.9%).[66] This is an expected finding,

[66] The chi-square tests for the ORGLINK variable are significant at the 1% level for all firms, at the 10% level for the science-based technology firms and at the 5% level for the mature technology firms, showing that the categories of this variable differ from each other.

since firms in the developing countries especially need to acquire their process technologies from abroad.

Table 6.1 Distribution of links by origin and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
ORIGIN OF LINK (ORGLINK)	**Count**	**% links**	**Count**	**% links**	**Count**	**% links**
Foreign	233	57.1%	122	56.2%	111	58.1%
Domestic	175	42.9%	95	43.8%	80	41.9%
of which inter-organizational	107	26.2%	54	24.9%	53	27.8%
of which intra-firm	68	16.7%	41	18.9%	27	14.1%
All	408	100.0%	217	100.0%	191	100.0%
ORGLINK *(*Chi-Square Test, asymp. sig.*)*	0.004		0.067		0.025	
FIRMTYPE vs. ORGLINK (Pearson Chi-square, asymp.sig. 2-sided)			0.700			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews

In Table 6.1, the Pearson chi-square test for FIRMTYPE vs. ORGLINK is not significant, indicating that the two variables are not associated with each other. This implies that the two segments of the industry behaved similarly in terms of the origins of their linkages. By inspection, it appears that the science-based and the mature technology firms' use of domestic and foreign sources were not very different from each other (for domestic sources 43.8% and 41.9% and for foreign sources 56.2% and 58.1%, respectively).

Table 6.1 also differentiates between the domestic inter-organizational (inter-firm and firm-institute) and intra-firm links as subsets of domestic links. During the fieldwork it was observed that there was considerable activity going on within the firm and this is captured and highlighted by intra-firm sources – a point that is elaborated in detail in the next section.

6.2.2 Type of Knowledge Source

The type of source, i.e. whether it is a firm or institute or an intra-firm source, is identified as another characteristic of the system in this analysis.

Table 6.2 suggests that, from 1967 to 2001, firms in the industry were ***much more*** likely to collaborate with firms than institutes or to use intra-firm sources (60.0%, 23.3% and 16.7%, respectively.). Moreover, 51.2% of firm linkages were with foreign firms. This finding supports the earlier observation that more than half of the linkages were with foreign sources and probably process technology importation accounted for most of these relationships. Linkages with the institutes (i.e. universities and research institutes) hardly reached a quarter of all links. It is very interesting, however, to find that firms were ***more*** likely to collaborate with domestic institutes than foreign institutes (17.4% and 5.9%).

Table 6.2 Distribution of links by source of knowledge and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
TYPE OF SOURCE (SOURCE)	Count	% links	Count	% links	Count	% links
Firm	245	60.0%	119	54.8%	126	66.0%
of which foreign firm	209	51.2%	106	48.8%	103	53.9%
of which domestic firm	36	8.8%	13	6.0%	23	12.0%
Institute	95	23.3%	57	26.3%	38	19.9%
of which foreign institute	24	5.9%	16	7.4%	8	4.2%
of which domestic institute	71	17.4%	41	18.9%	30	15.7%
Intra-firm sources	68	16.7%	41	18.9%	27	14.1%
All	408	100.0%	217	100.0%	191	100.0%
SOURCE *(*Chi-Square Test, asymp. sig.*)*	0.000		0.000		0.000	
FIRMTYPE vs. SOURCE (Pearson Chi-square, asymp.sig. 2-sided)			0.073			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews

During the fieldwork it was observed that there was considerable activity going on within the firm itself. This is captured and highlighted by the introduction of intra-firm sources into the analysis.[67] From 1967 to 2001, these accounted for 16.7% of knowledge linkages in the industry.[68]

In Table 6.2, the Pearson chi-square test for FIRMTYPE vs. SOURCE is significant at the 10% level, indicating that the relationship between these two variables is suggestive but not conclusive. This implies that the two segments of the industry might have behaved differently in terms of the sources of their linkages. By inspection, it appears that the science-based technology firms were only a little ***less*** likely than the mature technology firms to collaborate with other domestic and foreign firms (54.8% and 66.0%) – i.e. foreign (48.8% and 53.9%) and domestic (6.0% and 12.0%). And they were only a little ***more*** likely than mature technology firms to collaborate with institutes (26.3% and 19.9%), both foreign (7.4% and 4.2%) and domestic (18.9% and 15.7%). They also conducted a little ***more*** intra-firm activity than the mature technology firms (18.9% and 14.1%).

6.2.3 Density of Links

The density of links is used as a measure to observe how vibrant the innovation system is in the materials industry in Turkey. 'Density' here means the frequency of links per firm per year. Similar data for technology projects are also provided in Table 6.3. First, in this section, the figures covering the whole period from 1967 to 2001 are discussed. Then, in the next sections, figures tracing changes over time are presented.

Calculations in Table 6.3 show that there are almost no differences between science-based and mature segments of the industry in terms of involvement in technology projects and establishment of knowledge linkages with third parties. From 1967 to 2001, science-based technology firms in the sample launched just a few ***more*** technology projects and established only a few ***more*** knowledge links in absolute numbers than the mature technology firms (148 and 122 for projects and 217 and 191 for linkages). Therefore, the number of projects per firm per year and the number of links per firm per year did not change much between the science-based and mature

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[67] 'Intra-firm links' are explained in section 3.6.2.2 of Chapter 3.
[68] The chi-square tests for the SOURCE variable are significant at the 1% level for all firms, for the science-based and mature technology firms, showing that the categories of this variable differ from each other.

segments of the industry (0.44 and 0.40 for projects and 0.64 and 0.56 for links). The link per project ratio did not change considerably either, between the science-based and the mature segments (1.47 and 1.57).

Table 6.3 Density of technology projects and links by industry

	For all firms[a]	**For science-based technology firms**[b]	**For mature technology firms**[c]
Number of projects	270	148	122
Number of links	408	217	191
Link/project ratio	1.51	1.47	1.57
Density of projects (per firm per year)	0.42	0.44	0.40
Density of links (per firm per year)	0.63	0.64	0.56

a 19 firms , b 10 firms, c 9 firms.
Source: Author's own calculations

As seen in Table 6.4, the density of links measure in relation to increments in technological capability levels of the firms shows interesting findings. It must be noted that, although normally a knowledge link can continue for several years as part of a technology project, in this analysis only the starting time of the link is taken into consideration in the calculations. They are calculated for the whole time span of 35 years between 1967 and 2001. From 1967 to 2001, on average for all firms in the industry, 0.56 links per firm per year yielded increments in operational capabilities or none at all; 0.17 links per firm per year yielded increments in product or process improvement capabilities; and 0.15 links per firm per year yielded increments in product or process development capabilities.

This was broadly similar in the two segments of the industry. However, the science-based technology firms had a few ***more*** links per firm per year that yielded operational capabilities or none in their current projects than the mature technology firms (0.66 and 0.50 links per firm per year); and they had a few ***more*** links per firm per year that yielded product or process development capabilities in their current projects than the mature technology firms (0.22 and 0.10 links per firm per year).

Table 6.4 Density of links by type of capability increment and type of firm (1967-2001)

Increments in capability acquired in projects	Average links per firm per year		
	For all firms [a]	For science-based technology firms [b,d]	For mature technology firms [c]
Operational capability or none	0.56	0.66	0.50
Capability for product or process improvement	0.17	0.20	0.15
Capability for product or process development	0.15	0.22	0.10

a N=408, b N=217, c N=191.
d The first science-based technology firm was established in 1969, so the period for this group of firms is 1969-2001.
Source: Author's own calculations

6.2.4 Changing Structure of the Innovation System

This section dwells upon the changes in interactions of the firms over time. As detailed in Chapter 3, the whole time span of the study is divided into three main sub-periods – i.e. 1967 to 1981, 1982 to 1996 and 1997 to 2001.

In Table 6.5, drawn from Appendix Tables D.1 to D.8, the Pearson chi-square test for PERIOD vs. ORGLINK is not significant when tested for all firms, indicating that the two variables are not associated with each other. This implies that the three sub-periods did not show any marked differences in terms of the origins of firms' linkages, whether domestic or foreign.

However, when controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. ORGLINK is significant at the 10% level for science-based technology firms, indicating that the evidence of a relationship between the two variables is suggestive but not conclusive, while it remains not significant for mature technology firms, indicating that the two variables are not associated in this context. This implies that the three sub-periods might have shown differences regarding the origins of firm linkages in the science-based segment of the industry, but not in the mature segment. By inspection in Table 6.5 the science-based technology firms decreased their proportion of foreign links from 72.7% during 1967-1981 to 49.6% in the sub-period 1997-2001. At the same time they also increased their proportion of domestic links from 27.3% to 50.4%. These changes were not as prominent in the mature technology firms. For example, 68.8 % of their links were with foreign sources in 1967-1981, and the proportion was still 60.4% in 1997-2001. This is probably because science-based industries that were building up their own technology development capabilities were more likely to be able to acquire the technology they needed from domestic origin sources, whereas the foreign origin sources remained the main source of technology for the mature segment of the industry over time. These findings suggest that for the science-based technology firms at least, the network structure was becoming internalised over time.

In Table 6.5, the Pearson chi-square test for PERIOD vs. SOURCE is significant at the 1% level when tested for all firms, indicating that the two variables are associated. This implies that the three sub-periods showed significant differences in terms of the sources of their linkages, whether firm, institute or intra-firm. Although the previous analysis stated that more than half of the linkages of the firms were with other firms over the whole period from 1967 to 2001, the proportions of inter-firm links were decreasing and those of institute links were increasing during the subsequent sub-periods, whereas intra-firm sources remained largely the same. For example, during 1967-1981 firms were not collaborating with institutes at all, whereas by 1997-2001, the collaboration rate with the institutes was almost one-third of their knowledge links. Moreover, the majority of these institute links were with domestic institutes (77% of all institute links) as the structure of the innovation system was becoming more internalised. Thus, the structure of the innovation system was shifting from inter-firm linkages to firm–institute linkages over time.

Controlling for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. SOURCE is significant at the 5% level for science-based technology firms and at the 1% level for mature technology firms, indicating that the two variables are associated in this context. This implies that the three sub-periods showed differences regarding the sources of firm linkages in both segments of the industry. By inspection of Table 6.5 inter-firm linkages were decreasing over time in both segments, while firm–institute linkages were increasing. Neither segment of the industry had any institute links at all during the 1967-1981, but the science-based technology firms had a slightly

larger proportion of institute linkages than the mature technology firms in 1997-2001 (31.8% and 26.1%). Over time, firms have been less dependent on foreign markets and more in collaboration with the domestic knowledge holders such as universities and research institutes. In an assessment report for technology incubators in Turkey, Oz (2000: 46, 69-73) states that although 74% of companies said that they would have set up their business anyway even if they had not been allocated a place at the centre, 37[69] out of 71 interviewed start-ups (52%) clearly stated that 'university relations' was their priority and the most important factor ahead of e.g. training, networking with other entrepreneurs, assistance with financing, marketing, customer contacts, cheap rent, etc., of their being in the incubator centre.

Table 6.5 suggests that, although intra-firm sources showed a stable behaviour over time for all firms, the two segments of the industry behaved differently. Use of intra-firm sources presented a more stable pattern in the science-based technology firms from the first sub-period to the third sub-period (18.2%, 15.6% and 20.9%), but a fluctuating pattern in mature technology firms (18.8%, 25% and 7.2%). During the final sub-period, the science-based segment of the industry was likely to use intra-firm sources considerably ***more*** than the mature technology firms (20.9% and 7.2%). The science-based segment of the industry was becoming more self-sufficient by investing in its more stabilized in-house development efforts over the years.

Finally, Table 6.5 suggests that the innovation system was getting more vibrant over time. The proportion of knowledge linkages per year was increasing. For example, during the 1967-1981 sub-period, the firms' proportion of all linkages were only 6.6%, but by 1997-2001, that proportion was 58.5%. These figures were almost the same in both segments of the industry. Another indicator, the density of links per firm per year, increased five-fold in 1997-2001 compared to 1967-81 (2.54 and 0.52), and four-fold compared to 1982-96 (2.54 and 0.72). Although the mature segment of the industry had a ***lower*** density of links than the science-based segment of the industry initially (0.39 and 0.73), but managed to catch-up with the latter in the final sub-period (2.47 and 2.62).

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[69] 23 of them operating in medium and high technology fields – i.e. electronics, information processing, advanced materials, robotics, megatronics, software development, chemical processes, etc., and 14 of them operating in low technology fields – i.e. furniture making, control instrumentation, automation, etc.

Table 6.5 Distribution of links by origin, source, period and industry categories (percentage of links)

Periods	For all firms[a]			For science-based technology firms[b]			For mature technology firms[c]		
	1967-1981	1982-1996	1997-2001	1967-1981	1982-1996	1997-2001	1967-1981	1982-1996	1997-2001
ORIGIN OF LINK (ORGLINK)									
Foreign	70.4	58.9	54.6	72.7	64.9	49.6	68.8	51.6	60.4
Domestic	29.6	41.1	45.4	27.3	35.1	50.4	31.2	48.4	39.6
TYPE OF SOURCE (SOURCE)									
Firm	81.5	63.1	55.8	81.8	64.9	47.3	81.3	60.9	66.7
of which foreign firm	70.4	53.2	47.9	72.7	57.1	41.9	68.8	48.4	55.0
of which domestic firm	11.1	9.9	7.9	9.1	7.8	5.4	12.5	12.5	11.7
Institute	0.0	17.0	29.2	0.0	19.5	31.8	0.0	14.1	26.1
of which foreign institute	0.0	5.70	6.7	0.0	7.8	7.8	0.0	3.1	5.4
of which domestic institute	0.0	11.3	22.5	0.0	11.7	24.0	0.0	10.9	20.7
Intra-firm	18.5	19.6	14.6	18.2	15.6	20.9	18.8	25.0	7.2
DENSITY OF LINKS									
Projects	7.4	33.7	58.9	4.7	33.8	61.5	10.7	33.6	55.7
Links	6.6	34.6	58.5	5.1	35.5	59.4	8.4	33.5	58.1
Links/project ratio	1.35	1.55	1.51	1.57	1.54	1.42	1.23	1.56	1.63
Density of links (per firm per year)	0.52	0.72	2.54	0.73	0.84	2.62	0.39	0.59	2.47
All links (count)	27	141	240	11	77	129	16	64	111
Pearson Chi-square Tests	**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**		
PERIOD vs. ORGLINK	0.254			0.053			0.350		
PERIOD vs. SOURCE	0.002			0.022			0.002		

a N=408, b N=217, c N=191.
Source: Author's interviews and own calculations

These findings point to the strengthening linkages and emergence of an innovation system in this particular industry, which gained especially fast pace over the last five years of this study.

Table 6.6 Density of links by type of capability increment, type of firm and by periods

Increments in capability acquired in projects	Average links per firm per year								
	For all firms [a]			For science-based technology firms [b,d]			For mature technology firms [c]		
	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01
Operational capability or none	0.53	0.48	1.02	0.73	0.52	0.87	0.36	0.43	1.18
Capability for product or process improvement	0.01	0.19	0.58	0.00	0.23	0.62	0.01	0.15	0.56
Capability for product or process development	0.00	0.04	0.94	0.00	0.10	1.14	0.00	0.00	0.73

a N=408, b N=217, c N=191.
d The first science-based technology firm was established in 1969, so the period for this group of firms is 1969-2001.
Source: Author's own calculations

In addition to these, the findings from Table 6.6 suggest that from the first sub-period (1967-1981) into the third sub-period (1997-2001), the density of links related to particular capabilities was also increasing. For example, during 1967-1981, firms that had acquired development capabilities in their current projects were likely to establish no links in any year, but by 1997-2001 this rate was 0.94 links per firm per year. The density of links for improvement capabilities and even operational capabilities increased from the first to the third sub-period for all firms.

The two segments of the industry behaved broadly in the same way. For example, both segments of the industry, in 1967-1981, had no linkages pertaining to the acquisition of development capabilities in their current projects, but by 1997-2001, science-based technology firms that had acquired product or process development capabilities in their current projects were likely to establish ***more*** links than the mature technology firms (1.14 and 0.73 links per firm per year). Moreover, the former yielded more linkages associated with improvement capabilities and operational capabilities during the third sub-period.

6.2.5 Summary

The current analysis found that the innovation system in the materials industry in Turkey became internalised over time, particularly for the science-based technology firms opting to collaborate with domestic partners more than foreign partners. The system also moved significantly towards links with non-firm organizations, mainly domestic universities and to some extent foreign institutes. In support of these findings, the density of links per firm per year increased five-fold from 0.52 in 1967-1981 to 2.54 in 1997-2001. Both the science-based and mature segments of the industry managed to increase their density of links significantly over time.

6.3 Technological Capabilities and System Characteristics

The analysis in this section focuses on the relationship between (a) key features of the way that firms' acquired technological capabilities and (b) system characteristics in the materials industry in Turkey. To do this, cross-tabulation analysis is used.

6.3.1 The Increment in Capability Variable (INCCAP) Revisited

As already explained in Section 5.3.1 of Chapter 5, the variable *Increment in Capability* serves to examine the role of technological capability in the analysis. Table 6.7 (reproduced from Table 5.7) shows how different levels of capability increments are distributed among total links of firms and how they change by firm type. The increment in technological capabilities from each knowledge link is divided into three categories: (i) capability increments in process and product development, (ii) capability increments in process and product improvement, (iii) capability increments in process operation or no capability acquired.

Table 6.7 suggests that, from 1967 to 2001, more than half of the firms' knowledge linkages resulted in increments in operational capabilities or none at all (53.0%). The rest of their links yielded increments in process or product improvement capabilities and development capabilities (23.0% and 24.0%, respectively).[70]

Table 6.7 Distribution of links by increment in capability (at time t) and industry categories

	For all firms[a]		For science-based technology firms[b]		For mature technology firms[c]	
INCREMENT IN CAPABILITY (INCCAP)	**Count**	**% links**	**Count**	**% links**	**Count**	**% links**
Operational capability or no capability acquired	216	53.0%	101	46.5%	115	63.2%
Of which operational capability	187	45.8%	85	39.2%	102	53.4%
Of which no capability acquired	29	7.1%	16	7.4%	13	6.8%
Improvement of product or process technology	94	23.0%	51	23.5%	43	22.5%
Development of product or process technology	98	24.0%	65	30.0%	33	17.3%
All	408	100.0%	217	100.0%	191	100.0%
INCCAP *(*Chi-Square Test, asymp. sig.*)*	0.000		0.000		0.000	
FIRMTYPE vs. INCCAP (Pearson Chi-square, asymp.sig. 2-sided)			0.005			

a N=408, *b* N=217, *c* N=191.
Source: Author's interviews.

In Table 6.7, the Pearson chi-square test for FIRMTYPE vs. INCCAP is significant at the 1% level, indicating that the two variables are associated with each other. This implies that the two segments of the industry behaved differently in terms of the level of additional technological capabilities they acquired from their knowledge links. By inspection, it appears that science-based technology firms acquired ***more*** product or process development capabilities and ***fewer*** operational capabilities from their knowledge links than the mature technology firms (30.0% and 17.3% of their links for development capabilities and 46.5% and 63.2% of their links for operational capabilities). However, the proportion of links that resulted in product or process improvement technologies did not vary between firm types (23.5% for the science-

[70] The chi-square tests for the INCCAP variable are significant at 1% level for all firms, science-based technology and mature technology firms, showing that the categories of this variable really differ from each other.

based segment and 22.5% for the mature segment). This general picture indicates the state of an industry with emphasis on process operation skills, yet with emerging technology imitation, generation and innovation skills.

In Table 6.8 (reproduced from Table 5.8), drawn from Appendix Tables D.9, D.10 and D.11, the Pearson chi-square test for PERIOD vs. INCCAP is significant at the 1% level when tested for all firms, indicating that the two variables are associated. This implies that the three sub-periods showed significant differences in the level of incremental technological capabilities that they acquired from their knowledge links. Over time, all firms increased their acquisition of development capabilities of a product or process from nil during 1967-1981 to more than one-third of all links in 1997-2001, and they almost halved their proportion of acquisitions of operational capabilities from 1967-1981 to 1997-2001.

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for PERIOD vs. INCCAP is significant at the 1% level for both science-based and mature technology firms, indicating that the two variables are associated in this context. This implies that for both types of firms the three sub-periods showed significant differences in the level of incremental technological capabilities that they acquired from their knowledge links. By inspection of Table 6.8, it appears that in both segments, the proportion of links that resulted in increments in operational capabilities decreased, but the equivalent for development capabilities increased over time. Nonetheless, as expected, firms in the science-based segment of the industry increased their acquisition of development capabilities during the 1997-2001 sub-period by ***more*** than the mature technology firms (43.4% and 29.7%). They also managed to decrease the proportion of their acquisition of operational capabilities from their knowledge links in the same sub-period by ***more*** than the mature technology firms (to 33.3% and to 47.4%, respectively).

Thus, it seems that the last five years analysed can be identified with emerging major changes in the two different segments of the Turkish materials industry. It was particularly the science-based technology firms that showed early signs of moving to a different technological trajectory in the third sub-period of the analysis. In the light of these findings, the next sections will discuss the influence of deepening firm-level technological capabilities on the characteristics and the structure of the innovation system in this particular industry.

Table 6.8 Distribution of links by increment in capability (at time t), period and industry categories (percentage of links)

	For all firms[a]			For science-based technology firms[b]			For mature technology firms[c]		
Periods	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01	1967-81	1982-96	1997-01
INCREMENT IN CAPABILITY									
Operational capability or no capability acquired	96.3	66.7	40.0	100.0	61.0	33.3	93.8	73.4	47.4
Improvement of product or process technology	3.7	27.0	22.9	0.0	27.3	23.3	6.3	26.6	22.5
Development of product or process technology	0.0	6.4	37.1	0.0	11.7	43.4	0.0	0.0	29.7
All links (count)	27	141	240	11	77	129	16	64	111
Pearson Chi-square Tests	**(asymp. Sig. 2-sided)**			**(asymp. sig. 2-sided)**			**(asymp. sig. 2-sided)**		
PERIOD vs. INCCAP	0.000			0.000			0.000		

a N=408, b N=217, c N=191.
Source: Author's interviews.

In presenting the association between the explanatory variable 'increment in capability'[71] and the dependent variables 'origin of link' and 'type of source',[72] differently from the analysis in Chapter 5, here the former is expected to cause changes in the latter. It is also expected that this relation cannot be simultaneous. The analysis focuses on the relation between the capability level that the firm has already and where it sources its technology from. Therefore, using the 'increment in capability' as a lagged variable could reduce any errors in the analysis arising out of simultaneity of causation. Furthermore, using past increments in capability as a proxy for stock capability levels is

[71] As explained previously in Chapter 3, 'increment in capability' is used as an explanatory variable in the innovation system analysis, whilst it was a dependent variable in the technological capability accumulation analysis in Chapter 5.
[72] The variable 'density of links' is only used in econometric analyses in Section 6.4 and not used in cross-tabulation analyses, since it is not a categorical but a numeric variable created especially for the regression analysis.

thought to be suitable for the aim of the analysis in this chapter. Hence in this section, 'increment in capability **at time t-2'**[73] is used as a proxy for level of stock capability at time t. Assuming that the increment in capability at time t-2 is absorbed fully by the firm and turned into the stock capability at time t, one can run cross-classification analyses to find out whether the acquired level of capability from the previous link (the lagged capability increment) leads to collaborating with domestic or foreign partners or with firms or institutes in the sample firms.

The results related to the materials industry in general are discussed and complemented with the discussions about the significant highlights for science-based and mature segments of the industry. Also, results of statistical tests (Pearson Chi-square tests) for cross-tabulations of the categorical data are presented under the tables.

The database used in these analyses is again the main dataset formed by 408 observations for links derived from face-to-face interviews in sample firms. However, since the 'increment in capability' variable is transformed into a lagged variable, a number of observations will be lost in the database due to this arrangement. Depending on the configuration of the database (a categorical pooled dataset formed by links of 19 firms), every first and second technology project of each firm will be lost. This amounts to 19*2=38 projects corresponding to exactly 51 knowledge links in the database. Thus, the final dataset used in cross-classification analyses in this section will comprise 408-51=357 observations.

6.3.2 The Structural Balance Between Foreign and Domestic Origins of Knowledge

In Table 6.9, drawn from Appendix Tables D.12, D.13, and D.14, the Pearson chi-square test for INCCAP vs. ORGLINK is significant at the 1% level when tested for all firms, indicating that the two variables are associated. This implies that the firms' acquired additional capabilities showed significant differences in terms of the foreign/domestic sourcing of knowledge that they used for later links. For all firms in the industry, the higher the level of capability acquired, the greater was the probability that they would subsequently use domestic sources. For example, firms that had acquired only operational capabilities or no additional capabilities at all in their

[73] It is thought that 2 years, rather than 1 year would be a more appropriate time span for the firm to learn from its links and accumulate the knowledge acquired.

knowledge links were likely to use domestic sources for only about one-third of their later knowledge links. For firms that had acquired capabilities for product or process development, that proportion was 48.8%. Interestingly, if the firms had acquired additional development capabilities, the proportion of domestic links tended to decrease in their subsequent links.

Table 6.9 Firms' acquired capabilities (at time t-2) and the origins of knowledge links (at time t) in innovation system (percentage of links)

Levels of additional capability acquired in earlier links	The origins of knowledge links: For all firms [a]		For science-based technology firms [b]		For mature technology firms [c]	
	Foreign	Domestic	Foreign	Domestic	Foreign	Domestic
Operational capability or none	68.4	31.6	65.6	34.4	70.9	29.1
Capability for product or process improvement	50.0	50.0	55.3	44.7	43.2	56.8
Capability for product or process development	51.3	48.8	47.2	52.8	59.3	40.7
All	60.2	39.8	57.9	42.1	62.9	37.1
Pearson Chi-Square Tests for INCCAP vs. ORGLINK (asymp. sig. 2-sided)	0.003		0.091		0.011	

a N=357, b N=190, c N=167.
Source: Author's interviews

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. ORGLINK is significant at the 10% level for science-based technology firms, indicating that the evidence of a relationship between the two variables is suggestive but not conclusive, and it is significant at the 5% level for mature technology firms, indicating that the two variables are associated in that context. This implies that the mature technology firms' acquired additional capabilities showed significant differences in terms of the foreign/domestic sourcing of knowledge that they used for later links, though this relationship appears somewhat weaker for the science-based technology firms. By inspection of Table 6.9, both kinds of firms behaved in broadly similar ways. The science-based technology firms that had acquired only operational capabilities or none in their knowledge links were a little ***more*** likely than mature technology firms to use domestic sources for later links (34.4% and 29.1%), and if they had acquired development capabilities they were also ***more*** likely than mature technology firms to use domestic sources (52.8% and 40.7%). Compared with the mature technology firms, firms in science-based industries that are building up limited innovative capabilities are likely to have to rely on foreign sources for the knowledge they need; but if they are building up their own technology development capabilities, they are more likely to be able to acquire the technology they need from domestic sources, especially since those domestic sources include their own intra-firm capabilities – a point that is elaborated in the next step of the analysis.

The broad relationship suggested here between the levels of capabilities acquired by firms and the sources of knowledge they used in subsequent knowledge links is consistent with two earlier observations: first, the levels of capability acquired by firms during their knowledge links appeared to increase over time (see Table 6.8), and second that the domestic/foreign balance in the sources of knowledge used by firms also changed over time from foreign towards domestic (see Table 6.5), although these changes were more influential on the science-based segment of the industry.

However, one question should be raised about the interpretation of this relationship: did the association between capability levels and the foreign/domestic sourcing of knowledge arise because firms were changing their behaviour over time? (i.e. they would be deepening the capabilities they acquired during projects and also changing the sources of knowledge they subsequently used). Or was the effect more the result of changes in the type of new entrant firms to the industry over time? (i.e. new firms entering the industry would be bringing with them high levels of capability together with an inherent propensity to draw relatively heavily on domestic sources for the knowledge they used in their projects).

Table 6.10 (drawing on Appendix Tables D.15 and D.16) throws some initial light on this. It divides the sample of firms into two cohorts: those that entered up to 1981 and those that entered from 1982 onwards. The Pearson chi-square tests for INCCAP vs. ORGLINK is non-significant when tested for periods of firm establishment, indicating that the two variables are not associated in this way, implying that with respect to the level of capability, the later cohort of firms behaved in much the same way as the earlier cohort: Over time they both deepened the level of capabilities they acquired, reducing the operational or none category and increasing their development capabilities. Also over time, with respect to the origins of their knowledge inputs for links, they both shifted away from foreign towards domestic and intra-firm origins of knowledge sources in similar directions. This suggests that there was no significant cohort entry effect, and that this important aspect of the structure of the innovation system was changing primarily because incumbent firms in the industry, both new and old, were changing, not because new kinds of firms were entering the industry.

Table 6.10 Capability levels and sources of knowledge by cohorts of firm and time period

PART A	**Levels of Additional Capability**			
Types of firms and time periods	**Operational capability or none (%)**	**Improvement capability (%)**	**Development capability (%)**	**Total (%)**
Firms established up to 1981[a]				
In links 1967-1981	100	-	-	100
In links 1982-1996	63.6	25.0	11.4	100
In links 1997-2001	47.8	20.0	32.2	100
Firms established 1982 onwards[b]				
In links 1982-1996	74.2	21.0	4.8	100
In links 1997-2001	42.2	28.6	29.3	100

PART B	**Origins of Links**			
	Foreign (%)	**Domestic**		**Total (%)**
		Intra-organizational (%)	**Intra-firm (%)**	
Firms established up to 1981[a]				
In links 1967-1981	92.9	7.1	-	100
In links 1982-1996	63.6	25.0	11.4	100
In links 1997-2001	60.0	26.7	13.3	100
Firms established 1982 onwards[b]				
In links 1982-1996	71.0	21.0	8.1	100
In links 1997-2001	51.7	33.3	15.0	100

Pearson Chi-square Tests for INCCAP vs. ORGLINK by period of establishment (asymp. sig. 2-sided)

Firms established up to 1981	
1967-1981	-
1982-1996	0.112
1997-2001	0.303
Firms established 1982 onwards	
1982-1996	0.295
1997-2001	0.450

[a]N=148, [b]N=209

6.3.3 The Structural Balance Between Firm, Institute and Intra-firm Sources of System

In Table 6.11, drawn from Appendix Tables D.17, D.18 and D.19, the Pearson chi-square test for INCCAP vs. SOURCE is significant at the 1% level when tested for all firms, indicating that the two variables are associated. This implies that the firms' acquired additional capabilities showed significant differences in terms of the firm/institute/intra-firm sourcing of knowledge that they used for later links. In the industry as a whole, the higher the level of capability acquired, the lower was the proportion of collaboration with other firms, but the higher was the proportion of collaborating with institutes such as universities and other research institutes.

Table 6.11 Firms' acquired capabilities (at time t-2) and the types of source (at time t) in innovation system (percentage of links)

Levels of additional capability acquired in earlier links	The types of knowledge source: For all firms [a]			For science-based technology firms [b]			For mature technology firms [c]		
	Firm	Institute	Intra-firm	Firm	Institute	Intra-firm	Firm	Institute	Intra-firm
Operational capability or none	72.5	17.1	10.4	66.7	21.1	12.2	77.7	13.6	8.7
Capability for product or process improvement	51.2	34.5	14.3	48.9	34.0	17.0	54.1	35.1	10.8
Capability for product or process development	50.0	35.0	15.0	47.2	32.1	20.8	55.6	40.7	3.7
All	62.5	25.2	12.3	56.8	27.4	15.8	68.9	22.8	8.4
Pearson Chi-Square Tests for INCCAP vs. SOURCE (asymp. sig. 2-sided)	0.001			0.136			0.007		

a N=357, b N=190, c N=167.
Source: Author's interviews

For instance, firms that had acquired only operational capabilities or none at all in their knowledge links were likely to collaborate with universities and research institutes for as little as 17.1% of their subsequent knowledge links in later projects. For firms that had acquired capabilities for product or process improvement and development, that proportion was 35% for each category of capability. By contrast, firms that had acquired only operational capabilities or none at all in their knowledge links were likely to collaborate with other firms for almost two-thirds of their later knowledge links. For firms that had acquired capabilities for product or process development, that proportion was 50%. Firms' acquired additional capabilities did not vary much regarding the intra-firm sources. Firms that had acquired only operational capabilities or none at all in their knowledge links were likely to use their intra-firm sources for 10.4% of their later links; if they acquired improvement capabilities this proportion was 14.3%; and if they acquired development capabilities it was 15%.

Controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. SOURCE is non-significant for science-based technology firms, indicating that the two variables are not associated in that case, but it is significant at the 1% level for mature technology firms, indicating that there the two variables are associated. This implies that the mature technology firms' acquired additional capabilities showed significant differences in terms of the firm/institute/intra-firm sourcing of knowledge that they used for later links. However, the science-based technology firms' acquired additional capabilities did not show differences in such terms. By inspection of Table 6.11, in the science-based technology firms, the proportion of links with either firms or institutes or intra-firm sources did not differ much according to whether firms acquired improvement or development capabilities from their previous links. This might be due to the fact that at advanced levels of capabilities science-based technology firms' interactions with institutes tend to diminish slightly, maybe because institutes are not satisfactory enough for providing the knowledge that science-based technology firms need, or there are some other reasons. Nonetheless, at any capability level, the science-based technology firms were always somewhat ***less*** likely than mature technology firms to collaborate with other firms for later links (66.7% and 77.7% for operational capabilities; 48.9% and 54.1% for improvement capabilities and 47.2% and 55.6% for development capabilities). Except for when they had acquired just operational capabilities or none in their knowledge links, they were also a little ***less*** likely than mature technology firms to collaborate with institutes for their subsequent links (21.1% and 13.6% for operational capabilities, 34.0% and 35.1% for improvement capabilities and 32.1% and 40.7% for development capabilities). However, they were ***more*** likely to make use of their intra-firm sources in their knowledge links than the mature technology firms (12.2% and 8.7% for operational capabilities, 17.0% and 10.8% for improvement capabilities and 20.8% and 3.7% for development capabilities).

The broad relationship suggested here between the levels of capabilities acquired by firms and the type of sources they used in subsequent links is consistent with two earlier observations: first, the levels of capability acquired by firms during their knowledge links appeared to increase over time (Table 6.8), and second, the firm/ institute/ intra-firm balance in the sources of knowledge used by firms also changed over time from firms towards mostly institutes (Table 6.5).

6.3.4 The Structural Balance Between Foreign and Domestic Origins of Knowledge by Firm, Institute and Intra-firm Sources of System

In this section, firm and institute links are further broken down to their source of origin – i.e. domestic or foreign. To do so, variables SOURCE and ORGLINK are combined into a joined variable SOURCE-2. [74] In Table 6.12, drawing from Appendix Tables D.20, D.21 and D.22, the Pearson chi-square test for INCCAP vs. SOURCE-2 is significant at the 1% level when tested for all firms, indicating that the two variables are associated. This implies that the firms' acquired additional capabilities showed significant differences in terms of the domestic or foreign firm/institute/intra-firm sourcing of knowledge that they used for later links.

In general, the higher the level of capability acquired, the greater was the probability that firms would subsequently collaborate particularly with domestic institutes and use their own intra-firm sources, while interacting less with foreign firms. For example, firms that had acquired only operational capabilities or none at all in their knowledge links were likely to use domestic institutes for only about one in ten of their later knowledge links. For firms that had acquired capabilities for product or process development capabilities, that proportion was almost one in three of their later links. This is an important observation. By recalling the findings of Chapter 5 and Chapter 6

[74] Analysis of multidimensional contingency tables can be very confusing. In Table 6.12 there are indeed four variables: INCCAP, SOURCE, ORGLINK and the control variable FIRMTYPE. Reynolds (1977: 93) states that in case of multiple relationships "the easiest but perhaps least satisfactory solution is to combine the independent variables into a joint variable and then measure its relationship to the dependent variable." Therefore, in Table 6.12, variables SOURCE and ORGLINK are combined into a joint variable SOURCE-2 for ease of interpretation.

that firm capabilities were deepening over time and the structure of innovation system was becoming internalised, the results tell us that firms were at the same time increasingly aiming at knowledge-seeking relations – i.e. universities and other research institutes. Moreover, in accordance with the internalisation of structure of the innovation system, these knowledge-seeking relations mostly tended to be with domestic institutes. According to the results of *Use of Technology Services Survey* applied to 1300 firms in the manufacturing industry in Turkey by TURKSTAT (Turkish Institute of Statistics) in 1998, 54.4% of firms contacted domestic universities and local research institutes seeking a solution to their technical/operational problems, and 25.2% of firms collaborated with them for development of new products, whereas foreign universities and research institutes attracted only 16% of the firms for the same kinds of aims (Taymaz, 2001: 133 and 142).

When controlled for the effects of the variable FIRMTYPE, the Pearson chi-square test for INCCAP vs. SOURCE-2 is non-significant for science-based technology firms, indicating that the two variables are not associated in such firms, but is significant at the 5% level for mature technology firms, indicating that the two variables are associated in this case. This implies that the mature technology firms' acquired additional capabilities showed significant differences in terms of the domestic and foreign firm/institute/intra-firm sourcing of knowledge that they used for later links, unlike the science-based technology firms. By inspection of Table 6.12, in the science-based technology firms, the proportion of links with domestic or foreign firm/institute or intra-firm sources did not differ much from their previous links, particularly regarding the firms' acquired improvement or development capabilities. The reasons were stated in the previous section. The relationship was significant for the mature segment of the industry. The higher the level of capability acquired, the greater was the probability that mature technology firms would subsequently collaborate particularly with domestic institutes and also foreign institutes and use less of their own intra-firm sources, while interacting less with foreign firms.[75]

[75] For the mature segment of the industry, domestic university departments and research institutes seem to be more helpful even at so-called advanced levels of capabilities for product and process improvement and development rather than operational capabilities. These comprise mature techniques of powder metallurgy methods, which are relatively easy to use and its related products as small bulk metal and ceramic parts (see Appendix A.6.1), which do not have many complexities compared to high-technology processes and products.

Table 6.12 Firms' acquired capabilities (at time t-2) and the types of knowledge source by origin of link (at time t) in innovation system (percentage of links)

Levels of additional capability acquired in earlier links	**The types of knowledge source by origin of link**														
	For all firms [a]					**For science-based technology firms** [b]					**For mature technology firms** [c]				
	For. Firm	**For. Institute**	**Dom. Firm**	**Dom. Institute**	**Dom. Intra-firm**	**For. Firm**	**For. Institute**	**Dom. Firm**	**Dom. Institute**	**Dom. Intra-firm**	**For. Firm**	**For. Institute**	**Dom. Firm**	**Dom. Institute**	**Dom. Intra-firm**
Operational capability or none	62.7	5.7	9.8	11.4	10.4	57.8	7.8	8.9	13.3	12.2	67.0	3.9	10.7	9.7	8.7
Capability for product or process improvement	42.9	7.1	8.3	27.4	14.3	44.7	10.6	4.3	23.4	17.0	40.5	2.7	13.5	32.4	10.8
Capability for product or process development	43.8	7.5	6.3	27.5	15.0	41.5	5.7	5.7	26.4	20.8	48.1	11.1	7.4	29.6	3.7
All	53.8	6.4	8.7	18.8	12.3	50.0	7.9	6.8	19.5	15.8	58.1	4.8	10.8	18.0	8.4
Pearson Chi-Square Tests for INCCAP vs SOURCE-2 (asymp. sig. 2-sided)	0.007					0.338					0.019				

a N=357, b N=190, c N=167.
Source: Author's interviews

On the other hand, the science-based firms that acquired only operational capabilities or none in knowledge links were a little ***more*** likely than mature firms to use domestic institutes for later links (13.3% and 9.7%). They were also ***more*** likely to use their own intra-firm sources for their later links (12.2% and 8.7%). This was mostly due to the fact that science-based firms transferred state-of-the-art process technologies from abroad and sought further guidance from domestic institutes about how to operate and troubleshoot the machines along with using their own sources of knowledge[76]; whereas mature technology firms mostly used low and medium level process technologies which did not require further acquisition of complex knowledge for operation.[77] On the other hand, if the science-based firms had acquired improvement and development capabilities, they were ***less*** likely than mature technology firms to use domestic institutes for later links (23.4% and 32.4% for improvement capabilities and 26.4% and 29.6% for development capabilities). But, they were ***more*** likely to use their own intra-firm sources for their later links (17.0% and 10.8% for improvement capabilities and 20.8% and 3.7% for development capabilities). This finding shows that the science-based segment of the industry was quite confident about its own links for the reasons explained earlier – i.e. better endowment of existing knowledge base and higher intensity of effort in the firm. As examined in detail in Chapter 5, managers' higher level academic specifications, higher percentage of researchers and engineers in total employees, efforts to conduct significant R&D and non-trivial design activities in the science-based segment of the industry contributed greatly and positively to the strength of their intra-firm sources, which could accumulate the technological capabilities to deal with sophisticated technologies over time.

[76] Novel and complex production technologies such as vapour deposition techniques (PVD, CVD and ion implantation) for the production of thin film ceramic coatings; injection moulding and resin transfer moulding (RTM) for the production of polymer matrix composites; hot isostatic pressing and ceramic injection moulding techniques for the production ceramic matrix composites (see Appendix A.6.2 and A.6.3) necessitate expertise and tight control of process parameters and applications. Firms, which have imported these technologies from foreign firms, often initially used technical assistance from domestic universities that to some extent could be useful in operating these technologies. Materials science departments of Turkish universities could have been very helpful to firms regarding such sophisticated techniques at the initial stages of their capability building process – i.e. operational capabilities mainly and process and product improvement capabilities in some cases. However, it seemed that for higher-level capabilities of process and product development related to the above complex technologies firms had to also considerably rely on their own intra-firm resources, especially if they opted for further developing such techniques.

[77] These were mostly simple cold pressing techniques used for production of intricate and small metal parts formed from metal powders (see Appendix A.6.1).

6.3.5 Summary

The current analysis of the firms in the materials industry in Turkey shows that firm-level capabilities shape the way the innovation system's interactions vary and change. As the level of firms' capabilities deepen, firm interactions increase and seem to shift around in moderate ways in plausible directions towards domestic agents, which predominantly are universities and to some extent intra-firm sources.

Firms in the materials industry that are building up imitative and innovative capabilities are likely to have to rely on foreign sources for the knowledge they need; but if science-based technology firms are building up their own technology development capabilities, they are more likely to be able to acquire the technology they need from domestic sources, especially since those domestic sources also include their own intra-firm capabilities. Having been less advantaged by means of their absorptive capacities – as revealed in Chapter 5 - the mature technology firms are more likely to rely on domestic agents for knowledge inflow in the first place, as their capabilities deepen.

6.4 Econometric Analyses

The frequency and cross-tabulation analyses in Sections 6.2 and 6.3 presented the broad characteristics of the system, their key changes and internal differences. Cross-tabulations can only inform us about whether there is any association between two sets of variables or not. They cannot, however, tell us much about the strength of a specific relationship within such sets of variables. Regression models can be set up including several explanatory variables and they are able to tell us about the *strength* and the *direction* of the relation between each explanatory variable and a dependent variable. This section will introduce the results obtained from these econometric analyses.

The dataset used in this part of analysis is derived as explained in Section 3.7.1 of Chapter 3. The primary dataset with 408 observations is transformed into a new firm-specific and numeric dataset with 209 observations by re-arranging (adding up) the number of links for each category of the variables of the primary dataset for each firm over three-year intervals. In this way, a smaller range of numeric (not categorical any more as was the case for the primary dataset) pooled dataset is obtained for the linkages of 19 firms in the sample for the total period of 1967 to 2001 arranged in three-yearly intervals. What was the category of a variable in the primary database becomes an individual variable in the new dataset (e.g. Origin of link is a variable in the primary dataset with the categories as foreign link and domestic link, each of which becomes a single variable in the new dataset.). Since there are three different technological capability levels in the new dataset, each will be individually regressed against the dependent variables to assess their effects on the innovation system.

Further, as acknowledged earlier, the expected relationship between system characteristics and the capability increments implies a time lag. Capability increments in one sub-period may influence the structure of the system in a later sub-period. Therefore, variables are constructed to represent time-lagged capability increments in the models, as was previously done for cross-tabulation analyses.
It must be noted that because the data in this new database is arranged in three-year intervals, they already involve a time-lag. Despite that, in the models a lagged capability variable (with a lag of 6 years in total), which would capture the effects of a further backward three years on the dependent variables, is introduced. The results from the regression models are consistent with the results obtained from cross-classification analysis. The capability variables representing the current three-year intervals are all strongly related with the dependent variables, proving that capabilities shape the way the innovation system's interactions move around. However, the lagged capability variables yielded some interesting results.

Table 6.13 Descriptive statistics for variables of system analysis used in regression models

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
operationalcapability	209	0	11	1.02	1.864
improvementcapability	209	0	8	.45	1.069
developmentcapability	209	0	10	.47	1.584
foreignlink	209	0	16	1.11	2.289
domesticinterfirmlink	209	0	8	.51	1.286
intrafirmlink	209	0	6	.33	.909
firm	209	0	18	1.17	2.353
institute	209	0	8	.45	1.293
foreignfirm	209	0	15	.99	2.033
foreigninstitute	209	0	4	.11	.496
domesticfirm	209	0	3	.18	.512
domesticinstitute	209	0	8	.33	.977
density of links per year	209	.00	7.00	.6475	1.21672
Valid N (listwise)	209				

In Table 6.13, the descriptive statistics are presented for the variables of the new dataset. Looking at these statistics, one can understand from the minimum and mean values that the dataset will host a considerable number of zeros. Statistical package STATA offers zero-inflated negative binomial techniques to deal with excessive numbers of zeros in the analysis. However, this was not available in my statistical package, SPSS. I have used the Ordinary Least Squares (OLS) technique, which can be biased in these situations, but I still assume that OLS will cover most of the problem. The reasons to why other statistical methods are not used in this analysis are explained in Section 3.7.1 previously. In addition, it may be noted that, before having decided to settle on the OLS regression analyses, I tried binary logistic regression and also multinomial logistic regression on the primary dataset with categorical variables. The results obtained were not satisfactory and the variables and models were statistically insignificant. Therefore, I did not consider further use of these methods.

The partial correlation tests reveal that the capability variables are significantly correlated with each other (Table 6.14). To prevent further problems, which may arise with multicollinearity in the regressions, a different model is set up for each level of capability increment.

Table 6.14 Pearson correlation coefficients of explanatory variables in the regressions

	1	2	3	4	5	6	7
1.INCCAPoperational	1						
2.INCCAPimprovement	0.552**						
3.INCCAPdevelopment	0.494**	0.318**					
4.INCCAPoperational (lag)	0.172**	0.200**	0.389**				
5.INCCAPimprovement (lag)	0.163**	0.317**	0.359**	0.498**			
6.INCCAPdevelopment (lag)	0.177**	0.250**	0.235**	0.409**	0.307**		
7. Dummyperiod 1997-2001	0.541**	0.487**	0.582**	0.495**	0.510**	0.325**	
8. Dummyfirm science	-0.06	0.014	0.081	-0.033	0.026	0.117	0.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Along with the influence of the capability increments, the influence of type of firm – indicating science-based technology firms and the effect of time period on the innovation system –especially for the last five years studied, from 1997 to 2001,[78] is also of interest. Therefore, two dummy variables representing the above will be introduced into the models.

6.4.1 Linear Regression Models

Based on the ideas above, the models are formed as follows.

Model 6.1 Increments in Capability and Origin of Links

The first set of models assesses the effect of technological capability increments on the origin of links as to whether they are of foreign or domestic origin. There are in total 6 models formed to explain it. Equations 6.1a for operational capability, 6.1a' for improvement capability and 6.1a'' for development capability, drawn from Model 3.4 in section 3.7.3.2, assess the effects of capability increments on foreign links. Likewise,

[78] The density of links per firm per year have increased noticeably only in the third sub-period (1997-2001). The first sub-period (1967- 1981) and the second (1982-1996) show similar patterns for density of links (see Table 6.4). Thus, the effect of the last period only on the elements of innovation system will be checked, and the first two sub-periods regarded as a single period in the regression analyses. This approach will also be helpful in eliminating the concerns for collinearity between period dummies if two period dummies were to be introduced into the models.

equations 6.1b for operational capability, 6.1b' for improvement capability and 6.1b'' for development capability, drawn from the same model, assess the effects of capability increments on domestic links (in Table 6.15).

Equation 6.1a

Foreignlink = $\alpha_0 + \alpha_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or* INCCAPdevelopment$_t$ + α_2INCCAPoperational$_{t-1}$ *or* INCCAPimprovement$_{t-1}$ *or* INCCAPdevelopment$_{t-1}$ + α_3Dfirm$_{science}$ + α_4Dperiod$_{1997\text{-}2001}$ + u

Equation 6.1b

Domesticlink = $\beta_0 + \beta_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or* INCCAPdevelopment$_t$ + β_2INCCAPoperational$_{t-1}$ *or* INCCAPimprovement$_{t-1}$ *or* INCCAPdevelopment$_{t-1}$ + β_3 Dfirm$_{science}$ + β_4 Dperiod$_{1997\text{-}2001}$ + u

Model 6.2 Increments in Capability and Source of Knowledge

The second set of models assesses the effect of technological capability increments on the source of knowledge in the system, as to whether it is a firm, institute or intra-firm source. There are in total 9 models formed to explain it. Equations 6.2a for operational capability, 6.2a' for improvement capability and 6.2a'' for development capability, drawn from Model 3.5 in Section 3.7.3.2, assess the effects of capability increments on links with firms. Likewise, equations 6.2b for operational capability, 6.2b' for improvement capability and 6.2b'' for development capability drawn from the same model, assess the effects of capability increments on links with institutes. And equations 6.2c for operational capability, 6.2c' for improvement capability and 6.2c'' for development capability, again drawn from the same model, assess the effects of capability increments on links with intra-firm sources (in Table 6.16).

Equation 6.2a

Firm = $\alpha_0 + \alpha_1$INCCAPoperational$_t$ *or* INCCAPimprovement$_t$ *or* INCCAPdevelopment$_t$ + α_2INCCAPoperational$_{t-1}$ *or* INCCAPimprovement$_{t-1}$ *or* INCCAPdevelopment$_{t-1}$ + α_3 Dfirm$_{science}$ + α_4 Dperiod$_{1997\text{-}2001}$ + u

Equation 6.2b

$$\text{Institute} = \beta_0 + \beta_1\text{INCCAPoperational}_t \textit{ or } \text{INCCAPimprovement}_t \textit{ or } \text{INCCAPdevelopment}_t + \beta_2\text{INCCAPoperational}_{t-1} \textit{ or } \text{INCCAPimprovement}_{t-1} \textit{ or } \text{INCCAPdevelopment}_{t-1} + \beta_3 \text{ Dfirm}_{science} + \beta_4 \text{ Dperiod}_{1997\text{-}2001} + u$$

Equation 6.2c

$$\text{Intrafirmsource} = \delta_0 + \delta_1\text{INCCAPoperational}_t \textit{ or } \text{INCCAPimprovement}_t \textit{ or } \text{INCCAPdevelopment}_t + \delta_2\text{INCCAPoperational}_{t-1} \textit{ or } \text{INCCAPimprovement}_{t-1} \textit{ or } \text{INCCAPdevelopment}_{t-1} + \delta_3\text{Dfirm}_{science} + \delta_4\text{Dperiod}_{1997\text{-}2001} + u$$

Model 6.3 Increments in Capability and Source of Knowledge by Origin

The third set of models assesses the effect of technological capability increments on the source of knowledge by origin, as to whether it is a foreign firm or institute or domestic firm or institute. There are in total 12 models formed to explain it. Equations 6.3a for operational capability, 6.3a' for improvement capability and 6.3a'' for development capability, drawn from Model 3.6 in Section 3.7.3.2, assess the effects of capability increments on links with foreign firms. Likewise, equations 6.3b for operational capability, 6.3b' for improvement capability and 6.3b'' for development capability, drawn from the same model, assess the effects of capability increments on links with foreign institutes. And equations 6.3c for operational capability, 6.3c' for improvement capability and 6.3c'' for development capability, drawn from the same model, assess the effects of capability increments on links with domestic firms. And equation 6.3d yields equations 6.3d for operational capability, 6.3d' for improvement capability and 6.3d'' for development capability, once again drawn from the same model, assess the effects of capability increments on links with domestic institutes (in Table 6.17).

Equation 6.3a

$$\text{Foreignfirm} = \alpha_0 + \alpha_1\text{INCCAPoperational}_t \textit{ or } \text{INCCAPimprovement}_t \textit{ or } \text{INCCAPdevelopment}_t + \alpha_2\text{INCCAPoperational}_{t-1} \textit{ or } \text{INCCAPimprovement}_{t-1} \textit{ or } \text{INCCAPdevelopment}_{t-1} + \alpha_3 \text{ Dfirm}_{science} + \alpha_4 \text{ Dperiod}_{1997\text{-}2001} + u$$

Equation 6.3b

$$\text{Foreigninstitute} = \beta_0 + \beta_1\text{INCCAPoperational}_t \textit{ or } \text{INCCAPimprovement}_t \textit{ or }$$

$INCCAPdevelopment_t + \beta_2 INCCAPoperational_{t-1}$ *or* $INCCAPimprovement_{t-1}$ *or* $INCCAPdevelopment_{t-1}$ $+ \beta_3 \; Dfirm_{science} + \beta_4 \; Dperiod_{1997\text{-}2001} + u$

Equation 6.3c

$Domesticfirm = \delta_0 + \delta_1 INCCAPoperational_t$ *or* $INCCAPimprovement_t$ *or* $INCCAPdevelopment_t + \delta_2 INCCAPoperational_{t-1}$ *or* $INCCAPimprovement_{t-1}$ *or* $INCCAPdevelopment_{t-1}$ $+ \delta_3 \; Dfirm_{science} + \delta_4 \; Dperiod_{1997\text{-}2001} + u$

Equation 6.3d

$Domesticinstitute = \gamma_0 + \gamma_1 INCCAPoperational_t$ *or* $INCCAPimprovement_t$ *or* $INCCAPdevelopment_t + \gamma_2 INCCAPoperational_{t-1}$ *or* $INCCAPimprovement_{t-1}$ *or* $INCCAPdevelopment_{t-1}$ $+ \gamma_3 \; Dfirm_{science} + \gamma_4 \; Dperiod_{1997\text{-}2001} + u$

Model 6.4 Increments in Capability and Density of Links

The fourth set of models assesses the effect of technological capability increments on the density of links per firm per year. There are in total 3 models formed to explain it. Equations 6.4a for operational capability, 6.4a' for improvement capability and 6.4a'' for development capability, drawn from Model 3.7 in Section 3.7.3.2, assess the effects of capability increments on density of links (in Table 6.18).

Equation 6.4

$Linkdensity = \alpha_0 + \alpha_1 INCCAPoperational_t$ *or* $INCCAPimprovement_t$ *or* $INCCAPdevelopment_t + \alpha_2 INCCAPoperational_{t-1}$ *or* $INCCAPimprovement_{t-1}$ *or* $INCCAPdevelopment_{t-1} + \alpha_3 \; Dfirm_{science} + \alpha_4 \; Dperiod_{1997\text{-}2001} + u$

6.4.2 The Estimates

6.4.2.1 Origin of Knowledge Links and Increment in Capabilities

Equations 6.1a and 6.1b of Model 6.1 are used to assess the effect of level of increments in technological capabilities on firms' sources of links – i.e. foreign or domestic. Estimation results are displayed in Table 6.15. The overall fit of each sub-model is statistically significant at the 1% level as indicated by F-test significance values, showing that the selected explanatory variables have significant explanatory power on the dependent variables. The R-square values are also reasonably high for each sub-model with values just over 0.50.

Table 6.15 shows that all of the estimated models achieved basically the same results. All of the three levels of increments in capabilities – i.e. operational, improvement and development – were strongly influential on both domestic and foreign linkages of the firms. Increases in any of the capability variables would result in increases in domestic and foreign linking by the firms. For example, an increase of 1% in the level of operational capability would result in an average increase of at least 0.99% in foreign links and 0.32% in domestic links of the firms. An increase of 1% in the level of improvement capability would result in an average increase of at least 0.92% in foreign links and 0.61% in domestic links of the firms. And an increase of 1% in the level of development capability would result in an average increase of at least 0.74% in foreign links and 0.42% in domestic links of the firms. As the level of capability increments increased, firms were likely to build more domestic links but fewer foreign links (for foreign links 0.99>0.92>0.74 in order for operational, improvement and development capabilities, while for domestic links the coefficients are 0.32<0.61>0.42, respectively). This finding is mostly consistent with the findings from the cross-tabulation analysis; however, additionally it also confirms that the advanced capability levels hinder domestic links, since firms were likely to build fewer links when their level of capability for development of product or process increased 1% compared to when their level of capability for improvement of product or process increased by the same amount (0.42% and 0.61%).

Table 6.15 Results of OLS regressions for Model 6.1

	Dependent variables					
	foreignlink			domesticlink		
Independent variables	**coefficient**	**t-value**	**Sig.**	**coefficient**	**t-value**	**Sig.**
	Model 6.1a			Model 6.1b		
Constant	-0.269	-2.272	0.024**	-0.029	-0.279	0.781
INCCAPoperational	0.985	21.052	0.000***	0.322	7.717	0.000***
INCCAPoperational (lag)	0.183	3.049	0.003***	0.004	0.076	0.939
Firmtype science-based	0.245	1.684	0.094*	0.028	0.214	0.830
Period dummy 1997-2001	0.608	2.383	0.018**	1.068	4.688	0.000***
Number of observations	209			209		
R square	0.795			0.484		
df	4			4		
F-test (significance)	198.201 (0.000)			47.929 (0.000)		
	Model 6.1a'			Model 6.1b'		
Constant	0.296	1.682	0.094*	0.072	0.754	0.451
INCCAPimprovement	0.921	7.484	0.000***	0.611	9.184	0.000***
INCCAPimprovement (lag)	-0.125	-0.837	0.404	-0.007	-0.088	0.930
Firmtype science-based	-0.013	-0.057	0.955	-0.062	-0.501	0.617
Period dummy 1997-2001	2.412	6.427	0.000***	1.099	5.415	0.000***
Number of observations	209			209		
R square	0.491			0.528		
df	4			4		
F-test (significance)	49.120 (0.000)			57.059 (0.000)		
	Model 6.1a''			Model 6.1b''		
Constant	0.547	3.246	0.001***	0.231	2.385	0.018**
INCCAPdevelopment	0.742	8.607	0.000***	0.416	8.394	0.000***
INCCAPdevelopment (lag)	0.092	0.831	0.407	0.023	0.357	0.722
Firmtype science-based	-0.206	-0.923	0.357	-0.157	-1.226	0.222
Period dummy 1997-2001	1.654	4.562	0.000***	0.903	4.330	0.000***
Number of observations	209			209		
R square	0.526			0.504		
df	4			4		
F-test (significance)	56.665 (0.000)			51.874 (0.000)		

***Statistically significant at 1% level. **Statistically significant at 5% level. *Statistically significant at 10% level.

The lagged capability variables cover a period of the last 6 years in the regressions. They did not appear to be statistically significant in the models. Only the lagged operational capability variable had a strong influence on foreign links. An increase of one percentage point in the level of the lagged operational capability variable (increments in operational capability or none) would result in an average increase of at least 0.18% in foreign links. This is an interesting finding, because it actually states that firms' acquisition 3 years or more earlier of higher level capabilities (i.e. for improvement and development) does not determine the way they shape their networking. But previously acquired operational capabilities would be strongly influential on foreign links. Since, this is an industry dependent on foreign technologies, it is probable that the firms' earlier acquaintances with foreign technology suppliers would be very important in keeping these relationships going. Whether the supplier provided satisfactory technical help in the aftermath of technology acquisition, which usually contributes an increment in its operational capabilities to the firm, would be taken into consideration by the firm in its later preferences for technology acquisition.[79]

Foreign and domestic linkages were also found to be strongly influenced in sub-period 3, from 1997 to 2001. For example, firms were likely to build 0.61% more foreign links and 1.07% more domestic links as their level of operational capability increased by 1%; some 2.41% more foreign links and 1.10% more domestic links as their level of improvement capability increased by 1%; and 1.06% more foreign links and 0.90% more domestic links as their level of development capabilities increased 1%, compared to previous sub-periods. This finding strongly points to the emergence of an innovation system within the last five years regarding this particular industry. However, it still shows the domination of foreign links over domestic links in the system as the capability levels increase (2.41>1.10 and 1.06>0.90).

Finally, one characteristic, firm type – i.e. science-based or mature – did not demonstrate a statistically significant effect on foreign or domestic linking by the firms. This finding is consistent with the findings from cross-tabulation analysis in section 6.3.2, where it was stated that both segments of the industry behaved in broadly similar

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[79] For the science-based segment of the industry, this would usually cover imported state-of-the-art process technologies such as Cathodic Arc PVD, Magnetron Sputtering PVD, Ion implantation, Resin Transfer Moulding (RTM), autoclave moulding, etc. For the mature segment of the industry, this would cover imported machines such as latest technology hydraulic and eccentric presses and complex system large capacity sintering furnaces, which the firms would need after-sale services from the technology supplier company abroad in order to fully and efficiently operate the machines (see Appendix A.6).

ways regarding the relationship between additional levels of capabilities and the origins of links.

6.4.2.2 Types of Knowledge Source and Increment in Capabilities

Equations 6.2a, 6.2b and 6.2c of Model 6.2 in Table 6.16, and also equations 6.3a, 6.3b, 6.3c and 6.3d of Model 6.3 in Table 6.17, are used to assess the effect of level of increments in technological capabilities on the kinds of knowledge source involved in the firms' technology projects. The overall fit of each sub-model is statistically significant at the 1% level as indicated by F-test significance values, showing that the selected explanatory variables have significant explanatory power on the dependent variables. The R-square values are also reasonably high for each sub-model with values around 0.50, though some models have low values of around 0.20.

Table 6.16 shows that all of the estimated models achieved basically the same results. All three levels of increments in capabilities (operational, improvement and development) were strongly influential on all kinds of sources in the innovation system – i.e. firm, institute or intra-firm source. Increases in any of the capability variables would result in increases in links with these sources. For example, an increase of 1% in the level of operational capability would result in an average increase of at least 1.04% in links with other firms, 0.26% in links with institutes and 0.17% in links with intra-firm sources. An increase of 1% in the level of improvement capability would result in an average increase of at least 0.90% in links with firms, 0.63% in links with institutes and 0.21% in links with intra-firm sources. And an increase of 1% in the level of development capability would result in an average increase of at least 0.75% in links with firms, 0.41% in links with institutes and 0.20% in links with intra-firm sources. As the level of capability increment increased firms were likely to build more institute links, but fewer firm links (for institute links 0.26<0.63>0.41 in order for operational, improvement and development capabilities, for firm links the coefficients are 1.04>0.90>0.75, respectively). Intra-firms sources appear not to be very much affected by increasing level of additional capabilities (parameters: 0.17<0.21<0.20). This finding is mostly consistent with the findings from the cross-tabulation analysis; however, additionally it reveals that the advanced capability levels hinder institute links, since firms were likely to build fewer links when their level of capability for development of product or process increased by 1% compared to when their level of capability for improvement increased 1% (0.63% and 0.41%). It is probable that institutes are more helpful to firms at the intermediate levels of capability.[80] Yet, they are still the preferred partners to be contacted by firms to cooperate at advanced levels of capabilities than at the operational level.

Table 6.16 Results of OLS regressions for Model 6.2

	Dependent variables								
	firm			**institute**			**Intra-firm**		
Independent variables	**coef.**	**t-value**	**Sig.**	**coef.**	**t-value**	**Sig.**	**coef.**	**t-value**	**Sig.**
	Model 6.2a			Model 6.2b			Model 6.2c		
Constant	-0.132	-1.175	0.241	-0.166	-1.453	0.148	-0.012	-0.135	0.892
INCCAPoperational	1.043	23.402	0.000***	0.263	5.845	0.000***	0.171	4.799	0.000***
INCCAPoperational (lag)	0.088	1.534	0.127	0.098	1.717	0.087*	0.008	0.164	0.870
Firmtype science-based	0.079	0.573	0.567	0.193	1.379	0.169	0.139	1.251	0.212
Period dummy 1997-2001	0.712	2.925	0.004***	0.965	3.919	0.000***	0.460	2.359	0.019**
Number of observations	209			209			209		
R square	0.824			0.404			0.243		
df	4			4			4		
F-test (significance)	238.833 (0.000)			34.610 (0.000)			16.357 (0.000		
	Model 6.2a'			Model 6.2b'			Model 6.2c'		
Constant	0.441	2.409	0.017**	-0.074	-0.760	0.448	0.072	0.824	0.411
INCCAPimprovement	0.900	7.027	0.000***	0.632	9.350	0.000***	0.212	3.476	0.001***
INCCAPimprovement (lag)	-0.229	-1.448	0.149	0.095	1.133	0.258	-0.125	-1.660	0.098*
Firmtype science-based	-0.177	-0.745	0.457	0.102	0.814	0.416	0.100	0.881	0.379
Period dummy 1997-2001	2.643	6.767	0.000***	0.868	4.209	0.000***	0.781	4.207	0.000***
Number of observations	209			209			209		
R square	0.478			0.518			0.210		
df	4			4			4		
F-test (significance)	46.617 (0.000)			54.782 (0.000)			13.583 (0.000)		
	Model 6.2a"			Model 6.2b"			Model 6.2c"		
Constant	0.678	3.866	0.000***	0.101	1.006	0.316	0.124	1.461	0.145
INCCAPdevelopment	0.747	8.334	0.000***	0.411	8.017	0.000***	0.204	4.701	0.000***
INCCAPdevelopment (lag)	0.031	0.266	0.791	0.084	1.278	0.203	-0.017	-0.299	0.765
Firmtype science-based	-0.362	-1.559	0.121	-0.002	-0.012	0.991	0.052	0.460	0.646
Period dummy 1997-2001	1.782	4.728	0.000***	0.775	3.591	0.000***	0.449	2.462	0.015**
Number of observations	209			209			209		
R square	0.515			0.475			0.239		
df	4			4			4		
F-test (significance)	54.251 (0.000)			46.068 (0.000)			16.014 (0.000)		

***Statistically significant at 1% level. **Statistically significant at 5% level. *Statistically significant at 10% level.

[80] Especially domestic universities seemed to be valuable sources of knowledge for the mature technology firms regarding the further improvement or imitation by reverse engineering of powder metallurgy techniques such as cold or hot pressing to produce bulk metal or ceramic products. They could also provide expert help at all stages of the production process regarding powder characterization, binder selection, product reliability, quality control tests for the products, etc.

Table 6.17 shows the estimated models in which kind of source (firm and institute) is broken down into the origin of link as foreign or domestic. All three levels of increments in capabilities (operational, improvement and development) were strongly influential on all kinds of sources in the innovation system – i.e. foreign firm, foreign institute, domestic firm or domestic institute. Increases in any of the capability variables would result in increases in number of links with these sources. For example, an increase of 1% in the level of operational capability would result in an average increase of at least 0.86% in links with foreign firms, 0.13% in links with foreign institutes, 0.19% in links with domestic firms and 0.13% in links with domestic institutes. An increase of 1% in the level of improvement capability would result in an average increase of at least 0.67% in links with foreign firms, 0.25% in links with foreign institutes, 0.23% in links with domestic firms and 0.36% in links with domestic institutes. And an increase of 1% in the level of development capability would result in an average increase of at least 0.63% in links with foreign firms, 0.11% in links with foreign institutes, 0.12% in links with domestic firms and 0.27% in links with domestic institutes. As the level of capability increment increased firms were likely to build fewer foreign firm links (coefficients: 0.86>0.67>0.63 in order for operational, improvement and development capabilities). As their additional capability levels increased from operational to improvement of product or process, firms were likely build more foreign institute, domestic firm and domestic institute links (013<025, 0.19<0.23 and 0.13<0.36, respectively). But as their additional capability levels increased from improvement to development of product or process, firms were likely build fewer foreign institute, domestic firm and domestic institute links (025>0.11, 0.23>0.12 and 0.36>0.27, respectively). This finding reveals that the industry's general capability level is the intermediate level and this shapes the way that networks move around. It again seems probable that both domestic and foreign institutes and domestic firms are more helpful to firms at the intermediate levels of capability. Yet, they are still the preferred knowledge holding bodies to be contacted by the firms to cooperate with at more advanced levels of capabilities than the operational. However, at all levels of capabilities, foreign firms are the most preferred partners by the firms in materials industry in Turkey, simply because they are the main providers of novel production technologies in an industry strongly dependent on importation of these new technologies.

Table 6.17 Results of OLS regressions for Model 6.3

Independent variables	Dependent variables of models											
	foreign firm			foreign institute			domestic firm			domestic institute		
	coef.	t-value	Sig.	coef.	t-value	Sig.	coef.	t-value	Sig.	coef.	t-value	Sig.
	Model 6.3a			Model 6.3b			Model 6.3c			Model 6.3d		
Constant	-0.168	-1.519	0.130	-0.101	-2.086	0.038**	0.035	0.851	0.396	-0.062	-0.692	0.490
INCCAPoperational	0.857	19.620	0.000***	0.128	6.685	0.000***	0.187	11.385	0.000***	0.131	3.732	0.000***
INCCAPoperational (lag)	0.128	2.290	0.023**	0.055	2.227	0.027**	-0.041	-1.929	0.055*	0.044	0.972	0.332
Firmtype science-based	0.146	1.079	0.282	0.098	1.651	0.100*	-0.067	-1.319	0.189	0.094	0.858	0.392
Period dummy 1997-2001	0.634	2.661	0.008***	-0.026	-0.247	0.805	0.078	0.868	0.387	1.002	5.209	0.000***
Number of observations	209			209			209			209		
R square	0.774			0.271			0.498			0.363		
df	4			4			4			4		
F-test (significance)	174.698 (0.000)			18.929 (0.000)			50.504 (0.000)			29.023 (0.000)		
	Model 6.3a'			Model 6.3b'			Model 6.3c'			Model 6.3d'		
Constant	0.339	2.071	0.040**	-0.043	-0.983	0.327	0.103	2.267	0.024**	-0.027	-0.347	0.729
INCCAPimprovement	0.670	5.855	0.000***	0.251	8.253	0.000***	0.230	7.280	0.000***	0.358	6.502	0.000***
INCCAPimprovement (lag)	-0.169	-1.195	0.233	0.042	1.107	0.269	-0.060	-1.542	0.125	0.073	1.068	0.287
Firmtype science-based	-0.068	-0.322	0.748	0.055	0.979	0.329	-0.109	-1.854	0.065*	0.047	0.458	0.648
Period dummy 1997-2001	2.393	6.859	0.000***	0.019	0.209	0.834	0.251	2.598	0.010**	0.858	5.115	0.000***
Number of observations	209			209			209			209		
R square	0.442			0.337			0.326			0.442		
df	4			4			4			4		
F-test (significance)	40.467 (0.000)			25.934 (0.000)			24.671 (0.000)			40.357 (0.000)		
	Model 6.3a''			Model 6.3b''			Model 6.3c''			Model 6.3d''		
Constant	0.530	3.474	0.000***	0.017	0.362	0.718	0.148	3.117	0.002***	0.080	1.033	0.303
INCCAPdevelopment	0.628	8.052	0.000***	0.114	4.658	0.000***	0.119	4.904	0.000***	0.268	6.787	0.000***
INCCAPdevelopment (lag)	0.103	1.023	0.308	-0.010	-0.332	0.741	-0.072	-2.312	0.022**	0.087	1.707	0.089*
Firmtype science-based	-0.244	-1.208	0.229	0.038	0.600	0.549	-0.118	-1.879	0.062*	-0.030	-0.294	0.769
Period dummy 1997-2001	1.510	4.602	0.000***	0.144	1.404	0.162	0.272	2.674	0.008***	0.707	4.249	0.000***
Number of observations	209			209			209			209		
R square	0.509			0.191			0.252			0.453		
df	4			4			4			4		
F-test (significance)	52.765 (0.000)			12.009 (0.000)			17.212 (0.000)			42.247 (0.000)		

***Statistically significant at 1% level. **Statistically significant at 5% level. *Statistically significant at 10% level.

Among the kinds of sources only foreign firms and domestic institutes were found to be statistically significant and strongly influenced in sub-period 3, from 1997 to 2001. For example, firms were likely to build 0.63% more foreign firm links and 1.00% more domestic institute links as their level of operational capability increased by 1%, 2.39% more foreign firm links and 0.86% more domestic institute links as their level of improvement capability increased 1%, and 1.51% more foreign firm links and 0.71% more domestic institute links as their level of development capability increased 1%, compared to previous sub-periods. This finding is striking in what it tells about a system where inter-firm relations in the domestic environment are very much undermined. It also informs about an industry with capability levels not enhanced enough to cooperate with high-level foreign institutes. And it still shows the domination of foreign firm links over domestic institute links in the system as the capability levels increase (2.39>0.86 and 1.51>0.71).

The lagged capability variables are found to be statistically significant and influential only on foreign firm and foreign institute links for the reasons stated earlier in section 6.4.2.1.

Finally, one characteristic, firm type (i.e. science-based or mature) did not demonstrate a statistically significant effect on the kinds of sources. Only in models 6.3.c' and 6.3.c'', where it relates to domestic firm links, was it statistically significant at 10% level. These findings are consistent with those from the cross-tabulation analyses in section 6.3.4, where it was stated that both segments of the industry behaved in broadly similar ways regarding the relationship between additional levels of capabilities and the kinds of source, but the science-based segment of the industry showed fewer interactions with domestic firms.

6.4.2.3 Density of Links and Increment in Capabilities

Model 6.4 is used to assess the effect of level of increments in technological capabilities on density of links. Estimation results are displayed in Table 6.18. The overall fit of each sub-model is statistically significant at the 1% level as indicated by F-test significance values, which shows that the selected explanatory variables have significant explanatory power on the dependent variables. The R-square values are also reasonably high for each sub-model with values over 0.60.

Table 6.18 shows that all of the estimated models achieved basically the same results. All three levels of increments in capabilities (operational, improvement and development) were strongly influential on density of linkages of the firms. Increases in any of the capability variables would result in increases in number of links in firms.

Table 6.18 Results of OLS regressions for Model 6.4

	Dependent variable Density of Links		
	coefficient	**t-value**	**Significance**
Independent variables	Model 6.4a		
Constant	-0.103	-1.894	0.060*
INCCAPoperational	0.493	22.820	0.000***
INCCAPoperational (lag)	0.065	2.342	0.020**
Firmtype science-based	0.137	2.044	0.042**
Period dummy 1997-2001	0.712	6.042	0.000***
Number of observations	209		
R square	0.846		
Df	4		
F-test (significance)	279.461 (0.000)		
	Model 6.4a'		
Constant	0.146	1.886	0.061*
INCCAPimprovement	0.581	10.700	0.000***
INCCAPimprovement (lag)	-0.086	-1.288	0.199
Firmtype science-based	-0.008	0.081	0.935
Period dummy 1997-2001	1.431	8.636	0.000***
Number of observations	209		
R square	0.669		
Df	4		
F-test (significance)	194.165 (0.000)		
	Model 6.4a''		
Constant	0.301	4.095	0.000***
INCCAPdevelopment	0.454	12.087	0.000***
INCCAPdevelopment (lag)	0.033	0.677	0.499
Firmtype science-based	-0.104	-1.068	0.287
Period dummy 1997-2001	1.002	6.343	0.000***
Number of observations	209		
R square	0.682		
df	4		
F-test (significance)	109.241 (0.000)		

***Statistically significant at 1% level. **Statistically significant at 5% level. *Statistically significant at 10% level.

For example, an increase of 1% in the level of operational capability would result in an average increase of at least 0.49% in density of links. A similar increase in the level of improvement capability would result in an average increase of at least 0.58% in density of links. And an increase of 1% in the level of development capability would result in an average increase of at least 0.45% in density of links. As the level of capability increment increased from operational to improvement firms were likely to build more links (parameters: 0.49<0.58), but as it rose from improvement to development firms were likely to build fewer links (parameters 0.58<0.45). This finding further proves that the industry in general is prone to more linkages in the intermediate state of capabilities.

Density of links is strongly influenced in the final sub-period, from 1997 to 2001. For example, firms were likely to build 0.71% more links as their operational capability increased 1%; 1.43% more links as their improvement capability increased 1%; and 1.00% more links as their development capabilities increased by the same amount, compared to previous sub-periods. This finding is striking in what it tells about the emergence of an innovation system with number of interactions rising as the level of firm capabilities increases, although currently concentrated on linkages that yield improvement capabilities.

6.4.3 Summary

The results from the linear regression analyses are consistent with the earlier findings from the cross-tabulation analyses. They also confirm that an increasing level of additional capabilities resulted in increasing number of linkages, especially with the domestic agents, which are mainly domestic universities. However, additional to these findings, regression analysis has found that advanced capability levels of product or process development, indeed actually hinder domestic linking. This is probably because domestic organizations cannot provide the advanced level of knowledge that firms do require at that level. Therefore, the density of links is expected to increase with increases in capability levels from process operation to product or process improvement; but it decreases with increases in capability levels from product or process improvement to development.

6.5 Conclusion

As also highlighted in summary sections throughout this chapter, the analysis of the firms in the materials industry in Turkey shows that firm-level capabilities shape the way the innovation system's interactions change. As the levels of firm capabilities deepen, firm interactions increase and seem to shift around in moderate ways in plausible directions towards domestic agents, which predominantly are universities. Therefore, the materials industry in Turkey became internalised over time by firms opting to collaborate with domestic partners more than foreign partners. Supporting these findings, the density of links per firm per year increased five-fold from 0.52 in 1967-1981 to 2.54 in 1997-2001. However, the regression analysis found that advanced capability levels of product or process development retard domestic links, probably because domestic organizations cannot provide the advanced level of knowledge that firms do require at that level. These effects were not very different in the science-based and mature segments of the industry. The regression analysis did not generally find the firm-type effect statistically significant.

It must be noted that, even though it is observed that the firms were increasingly opting to collaborate with domestic partners, foreign partners, and especially foreign firms – despite their share in total linkages consistently decreasing over time – remained as one of the main technology suppliers. Being located in a developing country, the materials industry is indeed largely dependent on foreign novel technologies. Also, given the fact that the vast majority of the knowledge links that were associated with domestic links were those that yielded capability increments in technology improvement, this tells us that the industry in general is at the stage of imitation. Therefore, it is quite reasonable for the firms to try to network with both the domestic and the foreign worlds.

Basically, it can be concluded that this is an innovation system making much use of firms beyond its national borders and institutes within the national borders. Links with the former are mostly based on importation of process technologies, while the links with the latter are more based on in-depth knowledge flow and knowledge generation in a bilateral environment. In firm-institute linkages there is a full potential of process and product technology imitation and generation that is also supported by firms' own sources, especially in the case of science-based segment of the industry. However, this is at a very embryonic stage, and whether an effective innovation system emerges or not depends on the success of these kinds of linkages. Nevertheless, the findings from the analyses in this chapter indicate the firm-driven nature of the innovation system, causally driven by the capabilities of the firm.

CHAPTER 7 CONCLUSIONS

7.1 Introduction: Research Questions

This thesis has analysed the extent to which technology transfer contributes to the improvement and development of technological capabilities through learning at the firm level in a developing country, and the impacts of this process on the emergence and alteration of key characteristics of innovation systems.

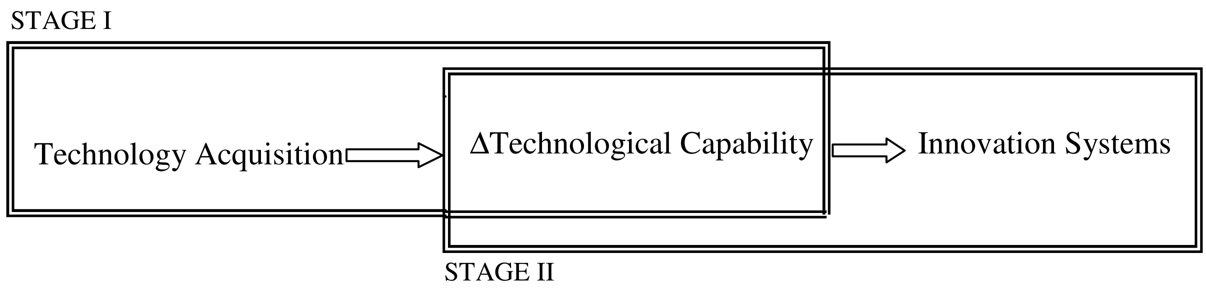
The study aimed to answer the principal research question below by staying within the boundaries of the 'firm' in the materials sector in Turkey:

- How do innovation systems emerge and change in a developing country context, and how are they influenced by the technology transfer process?

The analytical framework has designed for a firm-level analysis by which the technology acquisition process and the variables affecting the accumulation of firm-level technological capabilities act as ways of integrating knowledge for the firm and influence the innovation system. In other words, the strength of technological capability accumulation in the firm determines the degree of activity in the innovation system at large. Therefore, the firm's own inner capacity to activate capabilities and its linkages with the outside world are ways to approach the Systems of Innovation concept in a more focused manner. Therefore, a two-stage research structure has been designed (see Figure7.1, reproduced from Fig. 3.1 in Chapter 3) to work on the major objectives of the study and to answer the sub-questions below, which elaborate the main research question:

- How does the transfer of technology influence technological capabilities at the firm level in the materials industry in Turkey?
- How do the increments in technological capabilities from technology transfer processes influence the emergence and the elements of the system of innovation in the materials industry in Turkey?

Figure 7.1 Three key concepts used in this two-stage research



The thesis focuses on the relationship between three phenomena in Turkey:
(i) the ways in which firms in the materials industry acquired their technology;
(ii) the paths of technological capability accumulation followed by those firms;
(iii) changes over time in key features of the innovation systems within which these firms were embedded.

7.2 Summary of Research Design

As just emphasized, the overall research has been designed in two stages. The analysis of technology acquisition and technological capabilities at the first stage of research (see Figure 7.2 reproduced from Fig. 3.2 in Chapter 3), aimed to identify the extent to which selected characteristics of technology transfer process influenced the types of increment in technological capability acquired by the firms. These characteristics were: (i) the existing capabilities that the firm brought into the innovation process, as reflected in the number of researchers in the firm and managerial endowments such as academic skills and industrial expertise; (ii) the intensity of effort exerted by the firm, as reflected by R&D and design activities conducted by the firm; and (iii) the type of technology acquisition, ranging from arm’s length market transactions to collaborative means of acquisition. These variables were used as independent variables in multinomial logistic regression models with the technological capability increment variable used as the dependent variable.

Figure 7.2 The analysis of technology acquisition and technological capabilities: Key concepts and variables

Technology Acquisition Process ⟹ ΔTechnological Capability

*Existing knowledge base of the firm
*Intensity of effort by the firm
*Type of technology acquisition

* Increment in capability

The analysis of technological capabilities and innovation systems in the second stage of the research (see Figure 7.3 reproduced from Fig. 3.3 in Chapter 3) aimed to highlight the effects of elements of technology acquisition as reflected in the incremental technological capabilities in terms of the characteristics of an innovation system. These characteristics were defined in three categories: (i) the origin of link, whether it is domestic or foreign; (ii) the type of actor, whether it is a firm, an institute or an intra-firm source; and (iii) density of links measured as number of links per firm per year. Each of these variables was separately used as a dependent variable in linear regression models where the increment in capability variable was used as the independent variable.

Figure 7.3 The analysis of technological capabilities and innovation system: Key concepts and variables

ΔTechnological Capability ⟹ Innovation Systems

*Increment in capability

*Origin of link in the system
*Type of actor in the system
*Density of system

The data for this research were obtained from face-to-face interviews with the key informants in the firms. After pilot work conducted in May 2001, a sample of 19 firms was selected in the industry: ten from the science-based segment and nine from the mature segment. On the whole, the sample represented 25% of the industry. A two-fold division of the industry was introduced in this study:

(i) Science-based firms that are producing high technology products, identified by their functional properties and by the use of higher technology processes and use of R&D; and by their applications in high technology sectors such as telecommunications, complicated electronics, defence and aircraft, etc.

(ii) Traditional firms that are producing relatively conventional and mature products, identified by their structural properties and by the use of medium technology processes in production; and by their applications in medium technology sectors, such as ferrous and non-ferrous metal parts for the automotive sector, iron and steel, standard glass and ceramic sectors, standard electronics, etc.

The data were processed into a panel data structure where each observation was associated with a 'knowledge link'. A 'knowledge link' was defined as the kind of interaction between the firm and any one of the agents in the system of innovation (including the links originating from inside the firm, namely the intra-firm sources) through which primarily knowledge is transferred to the firm by any means of technology acquisition. This approach provided a total of 408 observations (which formed the main database) that could be used in particular aspects of the analysis and allowed for quantitative analysis methods to be used in the research. The 'knowledge link' is derived by using the 'technology project' concept to which several knowledge links were attached. It is defined as any type of activity that the firm undertakes for acquiring technology, as well as the specific production and research activities with knowledge flow. It is useful in finding and highlighting the details about each single interaction of firms and studying them in quantitative analyses. There were a total of 289 technology projects in the analysis, which paved the way for the procurement of 408 knowledge links to form the main database.

Cross-tabulation analyses were used to explore the relationships between the dependent and the independent variables initially. These analyses also helped to trace changes in the firms' technology acquisition characteristics, the level of their technological capabilities and the innovation system characteristics over time. Then, econometric analyses (namely multinomial logistic regressions and linear regressions), were applied to investigate the strength and direction of the relationships.

In summary, the exploration of the relationships examined in this research is based on the following approaches to data analysis:

- By cross-sectional analysis involving the pooled data covering the two segments of the industry and all time periods;
- By cross-sectional data analysis for each of the industry segments separately;

- By examining changes over time within each segment in the key variables and their relationships.

Analysing changes over time was conducted by the introduction of a time pattern into the analysis. This research covered 35 years from 1967 to 2001, with the earliest establishment of a firm in 1967. When determining the periods for analysis, two approaches have been considered: i) the allocation of knowledge links between the periods as representative and explanatory as possible; and ii) periods taking historical events in the Turkish economy into account. Three main sub-periods for 1967-1981, 1982-1996 and 1997-2001 have been thereby introduced to trace changes over time in the analysis.

7.3 Main Findings and Conclusions

This section summarises the empirical findings of this two-stage research structure in brief (from Chapters 5 and 6) and discusses these findings along with the findings from other works in the literature. This present study first aimed to provide a better understanding of what goes on inside the firms as they build their competence, and then looked into the changes in the interactions of these firms with other firms and institutes as their capabilities increased over time.

7.3.1 Technology Transfer and Technological Capability Increments

The first stage of the analysis found that the elements of technology transfer process positively influenced technological capability accumulation at the firm level. The analyses show that firm level capabilities were increasing over time during the period 1967 to 2001. Also, they were increasing over time with the increasing level of absorptive capacity in the firm and firm's involvement in collaborative agreements for technology transfer processes and intra-firm activities. Both the cross-tabulation analyses and the multinomial logistic regression analyses found that the effect of absorptive capacity and technology acquisition processes on technological capability increments was greater in the science-based segment of the industry. These results are elaborated as below:

(i) Modes of technology acquisition in firms in the materials industry in Turkey shifted over time towards collaborative agreements and firm-endogenous activities, which did require partnerships with third parties. Firm-level capabilities were also strongly influenced by the mode of technology acquisition chosen by the firm. The higher the level of capability acquired, the greater was the probability that they would have used their in-house sources and would have collaborated with other firms or institutes in the industry. Moreover, engaging in firm-endogenous activity and collaborative agreement types of technology acquisition in both kinds of firms was important for improving a link's risk-ratio of yielding capability increments, particularly in the development of a product or process compared to product or process improvement. A possible reason for this association was that these modes of transfer involved greater elements of active knowledge seeking on the part of the firms.

(ii) Firms' absorptive capacities significantly increased over time from 1967 to 2001 in the materials industry in Turkey. Firms progressively increased their awareness and use of the elements of their existing knowledge base – i.e. the percentage of researchers in the firm, the academic and industrial experiences of their managers. They also did increasingly better over time in terms of intensity of effort by the firm – i.e. R&D and design activities. As firms increased their existing knowledge base and exerted more intensity of effort in their research activities, their acquisition of additional capability levels from the technology projects tended to increase. Having greater numbers of researchers and engineers in the firm and managers with academic degrees in the activity field of the firm and conducting primary or active R&D and non-trivial design activities were all important for improving a link's risk-ratio of yielding capability increments both for improvement and development of a product or process. Moreover, the probability of acquiring development capabilities was greater than that of improvement capabilities if the firms had high levels of the intensity of effort – i.e. they invested heavily in primary and active R&D and non-trivial design activities. However, the probability of acquiring development capabilities were not different from that of improvement capabilities if the firms had high levels of the existing knowledge base – i.e. researchers-engineers as more than 50 per cent of the employees, or managers with academic degrees from universities abroad and at least from national universities.

The above findings suggest that the existing knowledge base in the firm and particularly the intensity of effort by the firm are substantially important factors leading to technological capability accumulation in the firms as Cohen and Levinthal (1990), Kim (1997, 1998, 1999), Westphal and et.al. (1985) and Lall (1992) have already stated in their works. Besides that aspect, the current research study has found that the mode of technology transfer has a complementary role to the absorptive capacity of the firm in accumulating technological capabilities. The fact that the higher the level of capability acquired, the greater was the probability that the firms would have used their own in-house sources and would have collaborated with other firms or institutes in the industry, indicates that a possible reason for this association was that these modes of technology transfer may have involved some elements of the tacit knowledge flowing into the firm and that helped elevate the level of technological capabilities the firm holds (Kim, 1998). Shifting modes of technology acquisition in firms in the materials industry in Turkey over time from arm's length relationships – i.e. import of machinery, know-how transfer, etc. – towards collaborative agreements and firm-endogenous activities as the level of their technological capabilities are elevated, also indicates that this industry looks as if it follows the technology trajectory from acquisition to assimilation and then to improvement as in the case of Korean and East Asian industries (Hobday, 1995; Kim, 1999). In realising these changes over time, the second sub-period, from 1982 to 1996, acted as a transition period for both kinds of firms, during which intermediate capabilities such as technology improvement or imitation were incubated. This capability accumulation was then transmitted to product or process generation and innovation capabilities in the third sub-period, especially regarding the science-based segment of the industry. Thus, it seems that the last five years under analysis can be identified with emerging major changes in the two different segments of the Turkish materials industry.

(iii) The science-based segment of the industry appeared to be better endowed than the mature segment of the industry in skilled workforce and managerial experience. Following from these, the strong base of existing knowledge in these firms allowed the science-based technology segment to behave more aggressively in R&D and design activities and conduct their intra-firm technology projects with support from knowledgeable outside partners, especially within the last five years studied in this research. Consequently, they had more proportion of knowledge links that yielded higher levels of additional capability acquisition compared to mature segment of the industry. Moreover, multinomial logistic regression analysis showed that being a science-based technology firm was important for improving a link's risk-ratio of yielding capability increments particularly in development of a product or process.

7.3.2 Technological Capability Increments and the Emergence of Innovation Systems

The second stage of the analysis found that firm-level capabilities shape the way the innovation system's interactions (based on knowledge flow) move around in the materials industry in Turkey. These are elaborated as follows.

(i) The structure of the innovation system interactions was becoming internalised at two levels. First, at the industry level, foreign knowledge links were being replaced by domestic knowledge links. Second, at the firm level, science-based firms in particular were opting more for in-house activities. System interactions also were strongly influenced by the level of technological capabilities in the firms. For all firms in both segments of the industry, the higher the level of additional capability acquired, the greater was the probability that the firms would subsequently use domestic sources. However, additional to these findings, regression analyses found that advanced capability levels of product or process development actually hindered domestic linking. It is probably because domestic organizations cannot provide the advanced level of knowledge that such firms require. Or in some other cases, it may be that the confidentiality of knowledge in highly complex product or process production could be important for the firm and that deters the firm from expanding its networks. Rojec and Jaklic (2001) observed similar patterns in their research based on surveys made with 26 firms from the car components industry of Slovenia. They found that relationships between suppliers and buyers tend to diminish as the type of product moves from high complexity to very high complexity. Therefore, the findings of this research point to the fact that increasing technological capabilities in the firm may lead to increasing number of interactions, but something certainly happens to cause firms to abstain from interacting further when technological capabilities reach advanced levels at which firms start to produce complex and high technology products or deal with complex processes.

(ii) Moreover, in the materials industry in Turkey from 1967 to 2001, the structure of the innovation system was shifting towards non-firm organizations, from inter-firm linkages to firm-institute linkages over time, mainly with domestic universities. Firm-level capabilities also determined the kind of partner chosen by the firm for later interactions. The higher the level of additional capability acquired, the lower was the proportion of collaborating with other firms, but the higher was the proportion of collaborating with institutes such as universities in the later projects. This was more emphasized in the mature segment of the industry. In the science-based segment of the industry this effect was combined with the tendency to use intra-firm sources as well, as the level of additional capabilities from previous links increased. However, in similar fashion to what has been stated above, regression analyses found that the additional capability levels of product or process development hindered links with domestic institutes and firms. The regression analysis further revealed that the firms' use of own sources of knowledge also increased as the level of capability acquired increased. However, the strength of these increases was less than the strength of increases for domestic linking.

Inter-firm interactions have been studied in the literature in different forms, sometimes as embedded in the innovation systems concept with emphasis on user-producer relationships as "the micro-foundation of the concept" (Lundvall, 1992b, 2007: 96) and sometimes within kinds of networks such as user-producer or buyer-supplier relationships (Hakansson, 1987; Von Hippel, 1988; Fagerberg, 1992; Hagedoorn and Schakenraad, 1990). The interactions with non-firm organisations have been investigated empirically elsewhere generally under the heading "university-industry relations" or "university-public and private research organisations" (Senker and Faulkner, 1992; Faulkner and Senker, 1994, 1995; Mansfield, 1995; Laursen and Salter, 2004; D'Este and Patel, 2007; Tether and Tajar, 2008). Thus, inter-firm and firm-institute interactions would be examined, for the most part, separately from each other, and even if they co-existed in the analyses they would mainly make use of patent data (Corrocher et al., 2007). Studying innovation systems, particularly in a developing country, necessitates looking into inter-firm and firm-institute interactions simultaneously and using data other than patents. If innovation system interactions are studied emphasizing knowledge flows (Gelsing, 1992; Bell and Albu, 1999; Giuliani and Bell, 2005; Dantas, 2006), this approach can pave the way for analysing basic knowledge sources in the system together based on firm-level technological capabilities and can allow for tracing changes in these interactions – and thus in the basic characteristics of an innovation system – over time.

(iii) The innovation system in the materials industry in Turkey was becoming more active over time. The proportion of knowledge linkages per year was increasing. The density of links per firm per year increased five-fold from 0.52 in 1967-1981 to 2.54 in 1997-2001. Although the mature segment of the industry had a ***lower*** density of links than the science-based segment initially in 1967-1981 (0.39 and 0.73), it managed to catch-up with the latter by 1997-2001 (2.47 and 2.62). Regression analysis found that the density of links was associated with increments in improvement and development capabilities more than with operational capabilities. Thus, increasing interactions were likely to yield outcomes with increments in improvement and development capabilities rather than operational capabilities or none at all. These findings point to the strengthening linkages and emergence of an innovation system in this particular industry, especially in the last five years studied in this research. Archibugi et al. (1999) state that systems are usually defined by the volume and characteristics of the linkages that bind them together, and thus denote a vibrant or an inert system.

(iv) Lastly, even though it is observed that the firms were increasingly opting to collaborate with domestic partners, nevertheless foreign partners, especially foreign firms – despite their share in total linkages consistently decreasing over time - remained as one of the main technology suppliers. In a late-industrialised country, the materials industry, as investigated in this study, continues to be largely dependent on novel foreign technologies. Previous findings also tell us that the industry in general is at the stage of imitation, where firms still do rely on new foreign-origin technologies. Links with the foreign sources of knowledge are mostly based on importation of process technologies, yet the links with domestic sources are more based on in-depth knowledge flow and knowledge generation in a bi-lateral environment. Nevertheless, the findings point to the firm-driven nature of innovation system, causally driven by the technological capabilities of the firm.

7.4 Research Contributions

7.4.1 Theoretical Contribution

Existing studies of the Innovation Systems concept all try to clarify it by composing definitions and aiming to form a general framework from a theoretical perspective. The first contribution of this thesis to the literature is its use of technological capabilities concept as a bridge between technology acquisition and the innovation system in the search for an answer to the question of how innovation systems emerge. This thesis points to the fact that the firm-driven nature of innovation systems is often ignored and claims that increasing firm interactions are indeed results of rising levels of technological capabilities in the firms. It is the already existing knowledge base and the intensity of effort in the firm that increase the ability to make sense of, assimilate, use and create new knowledge (Cohen and Levinthal, 1990; Kim, 1998,1999) leading to further strong interactive links among the firms and other actors of the system. Therefore, firm-level technological capabilities serve as a bridge and a useful tool of analysis from the technology transfer concept in developing countries towards the systems of innovation concept, where knowledge flows are to be focussed on rather than the broader context.

This is an important contribution because of the many limitations of the existing literature. First, the existing literature mainly dwells on technology transfer to the firm, leading to technological capability accumulation in the firm. This essentially treats the innovation system as isolated from other concepts. Studies from advanced country experiences have shown that an organized system provides a good habitat for the effective accumulation of technological capabilities and innovation (Nelson, 1993; Malerba, 2004). This is also valid for some industrializing and newly industrialized countries (Kim, 1993, 1998, 1999; Hobday, 1995; Katz, 1985, 1987) and needs to be elaborated. Second, innovation system studies generally base their foundations on a broad set-up of a system where governments hold key roles for determining the policies for the industrial structure. These policies would aim at increasing interactions among the partners of the system. However, these approaches embrace too many parameters, which complicate any empirical analysis. Third, because of such complications empirical studies on innovation systems concept are mainly confined to the use of ‘R&D intensity’ (R&D expenditure as percentage of GDP) as a measure. This may provide reliable results in the context of developed countries, but it would not offer reliable results in the studies of developing countries. Fourth, the majority of studies that have been pursued until now derive conclusions mostly regarding the developed countries. It seems that there is a greater than ever necessity to make more observations about how systems operate in many developing countries.

This research makes use of a knowledge network approach as an empirical tool, but does not undermine the cumulative role of studies conducted within the innovation systems approach that have clarified the vital ingredients of a system in its narrow definition, that is through its ‘actors’ and ‘interactions’. The knowledge network approach, by focussing on the knowledge flows, allows feasible empirical analyses with certain other measurable parameters such as technological capability levels (or increments).

A further contribution of this thesis to the literature is through tracing and highlighting the changes over time in the characteristics of the innovation system in a developing country. Though it has said a lot about the networks, actors and the institutional structures involved, very little of the innovation system literature has assessed the dynamics of the situation and can claim to show that ‘the system is changing over time’, particularly in a late-industrialised world.

7.4.2 Methodological Contribution

This research is based on a firm-centred approach and the methodological claim of this research is that Systems of Innovation studies regarding an industry should be conducted through in-depth studies of firms. In this thesis, the firm, being in the core of all systems of innovation concepts, is the relevant area to investigate the emergence of an innovation system. Being a dynamic production unit endowed with a certain level of technological capabilities and having linkages, which are both the causes and results of these capabilities, the firm remains the crucial element of all relevant treatments of the systems of innovation concept. However its role has been less commonly analysed when compared to some of the other agents – i.e. universities, private and public research institutes, governmental bodies, etc. This study has firstly tried to fill this gap.

Secondly, another element of strength in this research lies in the fact that the *'technology project'* and as derived from that, the *'knowledge link'* is used as the unit of analysis. By using the 'knowledge link' as the unit of analysis, it was possible to capture the concentration of interactions in the innovation system over a time period of 35 years. This allowed for two contributions: (i) by increasing the number of observations it allowed for the data to be configured in a way that could be used for the econometric analyses; and (ii) by permitting a dynamic analysis of firm interactions. Most studies about the developing countries are based on a static approach to networking. They rely on surveys done by statistical institutes at a certain year. They ask questions to firms, thus the unit of analysis is the 'firm', which is not operationally strong in the analyses of innovation systems. The firm as the unit of analysis, notwithstanding its central importance to the innovation system and its emergence, does not allow for a dynamic understanding of the structure of interactions in the system in detail.

7.5 Policy Implications

The first stage of the analysis (in Chapter 5) in this research found that the firm-level technological capabilities were increasing over time with increasing absorptive capacity levels in the firms in the materials industry in Turkey. Then, the second stage of the analysis (in Chapter 6) revealed that increasing levels of technological capabilities in these firms shaped the way that knowledge-based firm interactions were moving around and coming to form the dynamic structure of innovation system in this particular industry. In other words, the nature of firm-driven technological capabilities in the innovation systems was demonstrated in this research.

The policy infrastructure regarding the innovation system in Turkey is presented in Chapter 4. There, it is shown that some governmental bodies are given the task of establishing the national innovation system in Turkey. These bodies produced comprehensive reports (policy documents) over a time period of the last 15-20 years about what needed to be done to achieve the ultimate aim. What needed to be done consisted of improving partnerships between the firms and the universities, R&D support to firms, to increase number of researchers, etc., as it appeared from the policy documents. Some steps have been taken towards achieving these aims among a number of others reported in those policy documents, most of which have been inconclusive.

Firstly, if policy makers could address the improvement of technological capabilities in the firms besides the R&D activities, this could be an important step towards understanding the structure of an effectively functioning innovation system in the context of a developing country such as Turkey. Relative to past practice this matters, because R&D support programmes were used as the major policy tools to encourage firms to undertake R&D, and in the belief that this would establish the links between the firms and the institutes somehow constituting a national innovation system, in which firm-to-firm interactions were largely ignored. The innovation system concept was almost downgraded to an R&D support system in the Turkish science and technology policy documents. This approach has two drawbacks.

(i) Studies relying on R&D and R&D support data can shed light on a relatively small portion of the innovation system. According to the Turkish Statistical Institute, about 90% of manufacturing industry firms are not engaged in R&D activities at all in Turkey (Taymaz, 2001). In addition, even though the R&D support programmes applied since the 1990s are considered to be one of the most important implementations to establish and improve a national innovation system in Turkey (Taymaz, 2001; Ozcelik and Taymaz, 2008), the surveys conducted with the firms which received these R&D supports reveal that their main aim for applying for such R&D support is firstly the 'financial support', secondly 'prestige' and only then 'collaborating with research organisations' (Taymaz, 2001: 170).

(ii) In a developing country firm, there is a great deal going on in the firm in terms of technological capability accumulation activities, which is out of the scope of pure R&D activities and that may be captured by activities other than R&D. These studies based on R&D support data may shed some light on large firms that conduct R&D and are innovative. Such an approach may be justifiable in the developed country studies since many firms there do conduct R&D. However, it leaves untouched a considerable part of capability accumulation activities in the late-industralized world.

Secondly, the understanding of inward knowledge flows into the firms especially from sources outside the country (particularly foreign firms) as well as from sources inside the country is for some reason not very clear and not highlighted in Turkish policy documents. Whereas developed country firms acquire substantial amounts of knowledge from other firms and institutes within strategic and planned collaboration, this is not the case for many developing country firms. Yet, the developing country firms import process technologies (machine-embodied knowledge) from firms abroad, contact their suppliers for troubleshooting, etc. Although they are not strategically planned, these routine activities have an interaction dimension and bring knowledge into the firm. This generally implies a level of interaction among the firms themselves, which again is largely ignored in the Turkish science and technology policy documents. When this knowledge is improved and empowered in the firm complemented by the firm's own knowledge base, its level of capability increases. With their level of capabilities augmenting, firms turn to holders of knowledge and seek to cooperate with them. Therefore, giving more attention to inward knowledge flows from domestic and foreign firms and especially to how they are managed in more knowledge-seeking ways seems essential for the success of science and technology policies in Turkey.

As a result, in Turkey, it would be useful from the policy point of view, to consider the following points:

(i) Not to copy quite directly the innovation system structures implemented in the developed countries, because the developing countries have different mechanisms compared to the developed countries; and hence, not to downgrade the innovation systems concept to R&D support only; but to acknowledge the influence of other activities in the firms contributing to the elevation of firm-level technological capabilities;

(ii) Not to focus only on the interactions between the university and industry; but to give emphasis also to firm-to-firm interactions covering both domestic and foreign firms, and to acknowledge that the borders of an innovation system in a developing country are larger than its national borders.

In view of the firm-driven structure of firm interactions in Turkey as outlined above, the government's efforts for developing methods to improve firms' technological capabilities, instead of excessively focussing on the R&D concept, would be very supportive in increasing firms' interactions based on knowledge flows. This would in turn contribute positively towards the formation of the core of a functioning innovation system in the materials industry in the country, already supported with some level of innovation policy instruments. At the level of the wider economy, this would show its effects by increasing numbers of interactive, competitive and innovative firms setting the basis for a strong industrial structure and a secure economy with stable economic indicators and sustainable growth in the long-term. Such an improvement would also be extremely useful in Turkey's much sought after accession to the EU, a process which started as early as 1963, especially when she is asked to fulfil certain requirements to comply with the EU legislations regarding her economic setting. Furthermore, such achievements would also prepare the basis and pave the way for stronger competitiveness of Turkish firms in the materials sector if they were exposed to the full force of EU competition.

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APPENDIX A THE ADVANCED MATERIALS

A.1 Introduction

This is a technical piece of text with the purpose of explaining products and production systems in the materials industry as located within the field of materials science. It provides further insight for interested readers into the understanding of science-based and mature segment distinctions of the materials industries that is set as a basis of comparison in this thesis. There is a shortened section about issues widely presented here in Section 4.3 of Chapter 4.

A.2 Where to Place Advanced Materials Within the Scientific Disciplines? Materials Science and Engineering

Materials[81] are located within the field of materials science and engineering, which receives feedback both from materials science, basic knowledge of materials and materials engineering, which is applied knowledge of materials. Progress in advanced materials is endorsed by a range of sciences: Basic sciences such as mechanics, physics and chemistry; applied sciences such as metallurgy and engineering sciences like mechanical, civil, chemical, electrical, nuclear and aerospace.

Materials scientists and engineers work on some aspects of materials with the aim of understanding and controlling one or more of the four basic elements of the field (UNIDO, 1990a: 2):

1. The *properties* of the material make it interesting or useful creating a challenge for materials science;
2. *Performance*, the measure of usefulness of the material in actual conditions of application;
3. *Structure and composition*, which includes the arrangement of as well as the type of atoms that determine properties and performance;
4. *Synthesis and processing*, by which the particular arrangements of atoms are achieved.

Materials science serves as an intermediate science between natural sciences and engineering sciences. Materials science, obtaining knowledge from natural sciences and materials engineering, making use of the knowledge provided by materials science in applications side may easily complement or overlap with each other in their activities in search of new materials with improved properties and new processes leading to new products with better performances. Emerging unity and coherence of elements of materials science and materials engineering determine a combined materials science and engineering (MSE).

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[81] The literature on materials focuses on 'advanced' or 'new' or 'high technology' materials as different from traditional materials such as basic metals, wood, etc. However, there is not a clear and widely accepted distinction as to how materials could be classified. Throughout the thesis, I preferred 'materials' to 'advanced materials' phrase simply because it encompasses a wider range of materials than the latter. Thus, in a developing country, there are many firms dealing with materials such as simple metal parts, which would be classified as traditional materials in the literature. But in this piece of text, I would stay in line with the existing literature and discuss 'advanced materials'.

A.3 Definition and General Classification for Advanced Materials

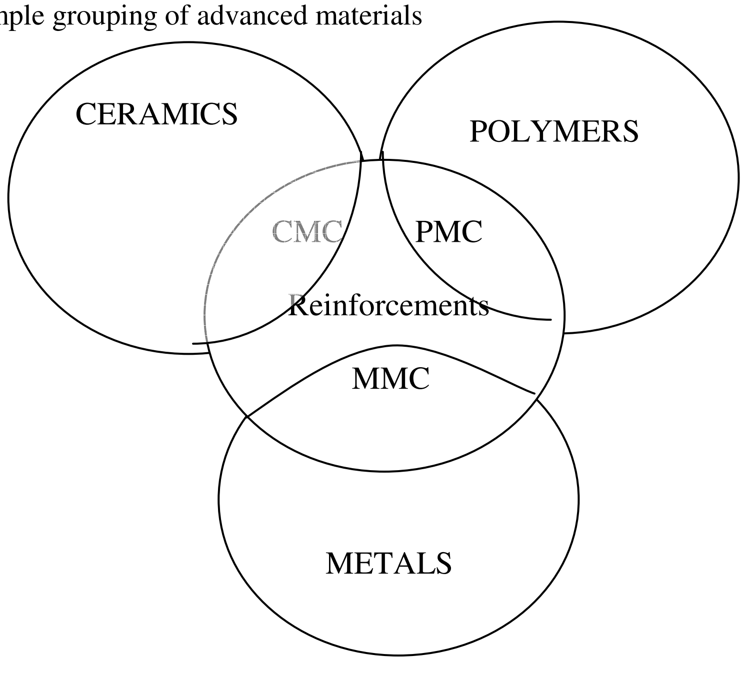
Advanced materials are defined as those to replace certain strategic materials, which will in turn catalyse major technological innovations. These include composite materials such as metals, polymers and ceramics reinforced with variety of fibres; structural and functional ceramics; structural polymers; rapidly solidified, microcrystalline and glassy metals; and innovations in surface engineering, in particular certain coatings designed to procure certain property advantages (Hondros, 1988).

Japanese definition of 'new materials' synonymous to advanced materials, is given as high value-added materials expected to have produced totally new epochal characteristics and new social values by driving sophisticated manufacturing processes and technologies and/or commercialisation technology based on metallic, inorganic and organic materials and their combinations, under four main headings: High performance polymers (organic), fine ceramics (inorganic), new metallic materials (metallic) and composite materials (Kaounides, 1995: 28-9). US Bureau of Mines similarly concentrates on four broad-based technologies: Advanced ceramics, advanced polymer composites, metal matrix composites and carbon-carbon composites. According to the US definition, advanced materials are polymers, metals and ceramics fabricated as inter-material compound, alloys or composites. The resultant components have higher strength-to-density ratios, greater hardness and wear resistance and one or more superior thermal, electrical or optical properties when compared with traditional materials. Advanced materials, the basis for many of today's emerging technologies, offer savings in total energy consumption, improved performance at reasonable cost and less dependence on imports of strategic and critical mineral resources (Cited from US Bureau of Mines, Annual Report, 1992 in Kaounides, 1995: 27).

As a result of evaluation of the definitions described above, advanced materials may be grouped very broadly under four main sets and their intersections as shown in Fig.A.1:

1. Metallic materials
2. Ceramics
3. Polymeric materials
4. Composites
    a. Metal matrix composites (MMCs)
    b. Ceramic matrix composites (CMCs)
    c. Polymer matrix composites (PMCs)

Figure A.1 Simple grouping of advanced materials



A.4 Taxonomy of Conventional and Advanced Materials

In order to be able to provide a satisfactory understanding of advanced materials, a classification is necessary and useful. Moreover, there is the need for advanced materials to be categorized within international statistics resources, in order to be able to collect reliable, consistent and comparable statistical series. Unlike groupings such as "agriculture, food, drink and tobacco; chemicals; energy; rubber; textiles and leather; minerals, ore and metals, …" in industrial production statistics, 'advanced materials' class does not exist, since its ingredients still are not properly classified so as to be accepted universally. The main reason for the difficulty of forming a reliable taxonomy is the continuous improvement of the industry itself, the introduction of both new products and new processes broadening the scope and applications of the industry, thus making the concept more complex. Determining the basis of classification, adopting a universal methodology is not an easy task. Materials scientists and social scientists follow dissimilar approaches in their attempts to classify advanced materials.

There are few approaches of social scientists trying to draw the boundary between conventional materials and advanced materials, such as "the growth rate of materials consumption" (Cohendet et al. 1988)[82]; "date of commercialisation criterion" (Theulon, 1989)[83]; "price per weight criterion" (Theulon, 1989)[84]; "value added and other special characteristics criteria"[85] as appears in the new materials definition of Japan's MITI Basic Materials Study Group. However, advanced materials are subject to continuous changes and improvements in time, exhibiting a very dynamic character. While a new product is introduced into the market, the previous substitute of it with less efficient properties may easily become obsolete and therefore left outside the boundaries of the chosen classification criteria. So, any classification under one of these headings needs to be revised continually and these attempts generally fail to end up with a universal methodology. The dynamic character of advanced materials must be reflected in the taxonomy in a static way. In attempting to define clearly and in a static way what is covered by the expression 'advanced materials', Theulon (1989) defines two classes of materials: Recent materials which are adopted by the industry and materials of the future, into which research is actively being conducted but which are not yet available in the market. Such an approach helps to distinguish between static and dynamic effects.

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[82] An advanced material would be any whose growth trajectory is in a phase of acceleration and anticipated growth rate on the next decade exceeds the average growth rate of the economy (Lastres, 1994:51-2). Cohendet et al. (1988) use this criterion based on a growth rate of about 3 per cent. Observatoire Des Materiaux Nouveaux of France has determined this level as 6 per cent. This approach calls for very recent data (Theulon, 1989). However, it faces the difficulty of finding reliable data, since until the beginning of 1990s there were absolutely no official statistics on advanced materials (Lastres, 1994:53). Currently, there is inconsistency in keeping statistics within countries. Only Japan has regularly held, reliable statistics stemming from her outstanding efforts to form taxonomy of the field within the boundaries of Japan.

[83] Advanced materials are defined as those, which have been adopted by the industry since the last 20-25 years.

[84] "Direct price per unit" cannot be a reliable and acceptable criterion because of serious difficulties such as the existence of rare and precious metals like gold, which definitely cannot be classified as an advanced material, but has a very high unit price. Secondly, production and consumption of advanced materials have different market structures that affect the prices.

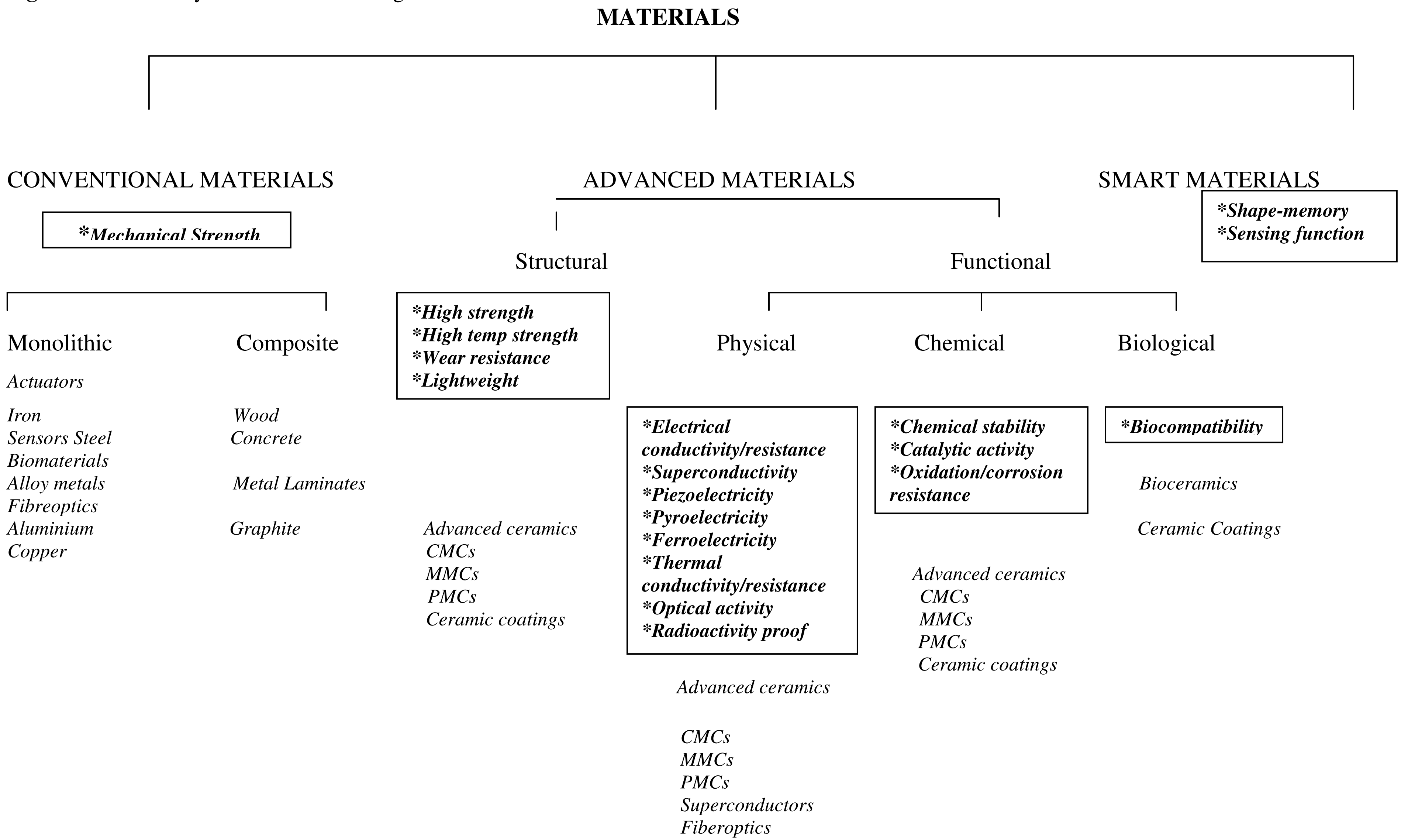
[85] It is very difficult to get statistics for value added, especially for those very recent and more specialised products (Lastres, 1994:55).

The ultimate essence of materials lays in the properties they do possess leading to their functions. For instance, wear resistance being a property provides the material with structural characteristics which function as protecting the product surface from abrasion. Similarly, electrical conductivity is a property providing physical functions. Materials do not lose their properties as time goes by, but materials with more improved and additional properties are introduced into the market as a result of ongoing R&D activities. In other words, earlier materials do not disappear; they are still there. They may even be improved by later technologies. Of course, overlaps and interactions are inevitable. Using taxonomy of functions approach may help to stabilize classification efforts both by keeping already existing materials and also providing new titles for groups of newly introduced materials, as illustrated in Figure A.2. Underlying this approach is there has always been a 'new' material specific to its time.

Conventional materials are principally characterized by their mechanical strength and are predominantly employed in load-bearing (Gandhi and Thompson, 1992:37) or compressive activities. Especially metals and metal alloys yield high tensile strength at room temperature, however it substantially decreases at higher temperatures. Therefore, their structural properties serve only for a particular mechanical function under limited conditions. Conventional composites have superior properties to those of monolithic materials. So, in the current literature most sole metals are not classified within advanced materials, but their combinations with other materials in the form of composites with improved properties is considered to be advanced.

Advanced functional materials are distinguished from conventional materials by their principal functional characteristics exploited in the fields of science and technology rather than the inherent mechanical properties of the latter (Gandhi and Thompson, 1992:38). Possessing either structural or functional or both kinds of characteristics, they can realize at least one or more functions and thus, are much superior to conventional materials. Structural, physical, chemical and biological functions are explained by properties obtained such as high thermal strength or insulation, high electrical conductivity or resistance, high chemical stability, piezoelectricity, pyroelectricity, corrosion resistance, wear resistance, etc. Smart materials of current generation contain a few functions of structure, shape-memory and sensing simultaneously. Thus, for example, a smart structure might feature a load-bearing graphite epoxy, fibrous polymeric structural material, in which are embedded piezoelectric discs for sensing purposes and embedded shape-memory-alloy wires for sensing purposes (Gandhi and Thompson, 1992:40).

Figure A.2 Taxonomy of materials according to their functions



A.5 Advanced Ceramics and Composites

The below sections will present information especially on ceramic and composite materials, which proved to have desirable properties and increasingly used in the industries. Metals, in the course of time, have been regarded as purely conventional materials, however, metal powders combined with each other and/or ceramic powders and pressed into sophisticated structures to form composites are widely used in automobile and cutting tool industries.

A.5.1 What is advanced ceramics?

Ceramics are neither organic nor metallic materials with elements bonded together primarily by ionic and/or covalent bonds (Smith, 1993:513) and formed as a powder and consolidated through firing at high temperature (Theulon, 1989). Advanced ceramics have improved and sophisticated characteristics.

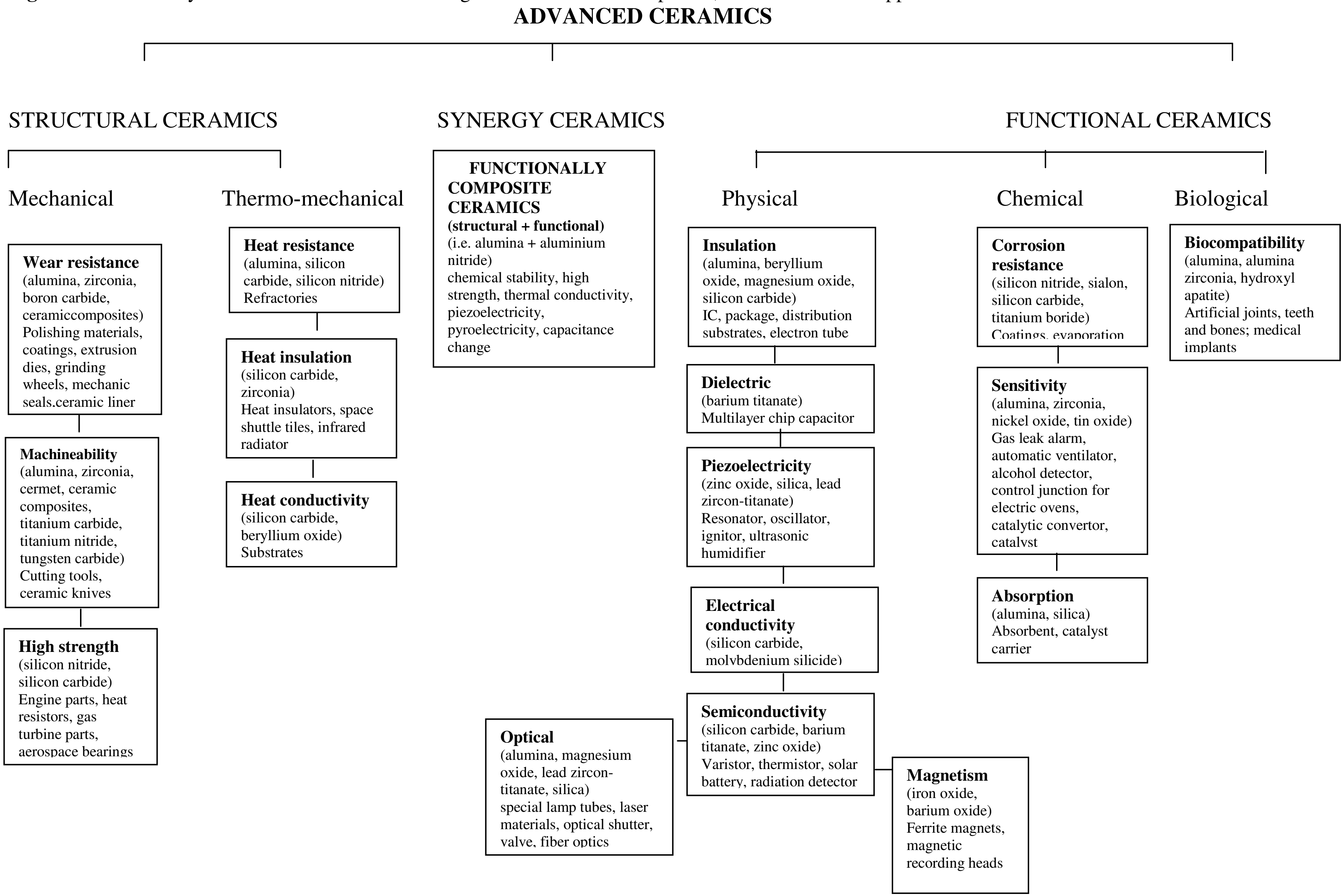
Traditional ceramics are used basically for bricks, tiles, tableware, sanitary fittings and in some cases porcelain electrical instruments. Advanced ceramics have applications precisely different from that of traditional ceramics. Thus, the first distinction between advanced and traditional ceramics comes out from the functions and thus applications point of view. The second distinction is indeed the main reason of first one, which is dependent on the raw materials used in production. Traditional ceramics are made of conventional raw materials clay, feldspar and silica (SiO_2). Compositions of advanced ceramics, on the contrary, include oxides, compounds containing oxygen atom such as alumina (Al_2O_3), titanium dioxide (TiO_2) and zirconia (ZrO_2) and non-oxides such as carbides in the form of silicon carbide (SiC), titanium carbide (TiC), boron carbide (B_4C); nitrides in the form of silicon nitride (Si_3N_4) and modified silicates; borides like titanium diboride (TiB_2); silicides like molybdenum disilicide ($MoSi_2$); technical glasses and various types of glass ceramics. Application fields of advanced ceramics strongly depend upon the type of raw material used, because the properties obtained by elemental structure provide specific functions. The distinctive properties of advanced ceramics will be dwelled upon in the following sections.

A.5.2 Classification, Properties and Application Fields of Advanced Ceramics

In Figure A.3, types of advanced ceramic and ceramic composite products are categorized according to their functions. For ease of understanding, only the predominant properties are highlighted in the figure. However, the reader should be aware that spillovers and multiple properties are highly likely in a particular product. Additionally, different types of ceramic materials have advantages and disadvantages for use in different applications, depending on possession of different properties.

The composition of a ceramic and the microstructure produced by the fabrication method are crucially important in determining the properties and performance. However, unlike the case with metals, this microstructure cannot usefully be changed by plastic working either at room temperature or at high temperatures. The vast majority of ceramics are fired to a high temperature at which the microstructures they finally possess are developed. Thus the product is normally accepted as it is supplied (Morrell, 1985). The production of any particular ceramic product with a specific function is closely associated with the selection of raw material already inherited with specific properties.

Figure A.3 Taxonomy of advanced ceramics according to their functions: Properties, raw materials and applications



In terms of properties discussed below, ceramics are mostly compared with metals. They do exhibit better characteristics in some cases, but in some other cases their characteristics are relatively poor. Basic and applied research is furthered continuously to improve poor characteristics of ceramics. The empirical work shows that today it is mostly possible by way
of improvements in the process technologies, which also adds value to the product. It is highly unlikely that ceramics may replace metals with their ordinary properties they do have
today, as opposed to the hopes in the 1970s. However, their fabrication with other materials in the form of composites is open to incremental improvements as well as radical improvements.

A.5.2.1 Structural Ceramics

Structural ceramics may be formed either from oxide ceramics or non-oxide ceramics distinguished especially with their hardness: diamond, silicon carbide, silicon nitride, zirconia, boron carbide, boron nitride, titanium carbide, titanium nitride, tungsten carbide, alumina and certain compounds of these elements such as titanium zirconium aluminium (TiZrAl). Another point is the very high melting points of the first elements (silicon, zirconium, boron, titanium, tungsten, molybdenium, yitrium, beryllium are metals and non-metals with melting points higher than 1500°C at least) of ceramic compounds.

Structural functions account for mechanical and thermo-mechanical functions, involving mainly properties of high load bearing, tensile, compressive and fracture strength, wear resistance and high temperature strength.

Ceramics can endure very high temperatures without melting unlike many metals. Nevertheless, because they are brittle, they cannot tolerate large internal strains imposed by thermal expansion mismatch. Moreover, each case needs to be taken on its own merits, since each material has its own composition and microstructure, which determine behaviour at high temperatures. Thus, thermodynamic factors such as specific heat, thermal expansion coefficient, thermal conductivity and diffusivity gain considerable importance in tackling with ceramic raw materials, which should be built upon profound research activities (Morrell, 1985:73).

Ceramics do not exhibit a reliable character for load bearing activities and do not yield high tensile and fracture strengths compared to many metals, either. Highly brittle character of ceramics causes micro cracks in the material to propagate so fast, thus resulting in application failures. This is mainly why during the last decades basic and applied research moved to investigate ceramic composites in combination with ductile metals, with the aim of increasing the toughness of ceramics, for use in mechanical applications requiring high tensile strength.
On the other hand, ceramics are incomparable to metals with regard to their high compressive strength, wear resistance and high temperature strength. Especially ceramic coatings promise great reliability for applications necessitating wear resistance. And that is why, the market share of ceramic coatings show a considerable rise within the industry and is expected so in the future.

As Chiang and Jakus (1999:8) draw attention to, remarkable improvements in toughness, hardness and strength of oxide and especially non-oxide ceramics have led to recent commercial successes such as development of cutting tools and forming dies with extreme hardness, chemical resistance and adequate toughness especially by the application of ceramic coatings. Similarly, zirconia ceramics with improved strength, toughness, corrosion resistance and wear resistance have saved millions of dollars in paper manufacturing and other industries. Thermally shock resistant insulation tiles enabled the Space Shuttle. Ceramic thermal barrier coatings extending upper use temperature of superalloy components became commercially successful, as well as being the focus of much current basic and applied research.

A.5.2.2 Functional Ceramics

Functional ceramics are formed by either oxide or non-oxide ceramics similar to structural ceramics. The first element of the compound, however, determines the main property of the material. Whilst metals (iron, tin, bismuth, aluminium, silicon, lead, zinc, titanium) make compounds with oxygen, nitrogen and carbon for magnetic, semiconductivity, piezoelectricity and ionic conductivity properties, non-metals (beryllium, barium, magnesium) form compounds with the latter to exhibit dielectrical, optical, insulation properties.

Functional ceramics are distinguished with their smarter physical, chemical and biological properties in comparison to structural ceramics. These products also serve for more advanced
industries such as electronics, computer software and hardware, semiconductor, chemical, health sector, domestic appliances, energy, home and industrial electricity and automobile.
They are responsible for scientific and technological innovations, which have contributed immeasurably to modern society. The zirconia oxygen sensor and 3-way automobile catalyst have enabled vast improvements in air quality; piezoelectric ceramic actuators have enabled technologies ranging from advanced sonar to scanning probe microscopies to the Hubble Telescope repair; ceramics packaging and multiplayer device technology have facilitated the continuing miniaturization of electronics and microwave dielectrics make present-day wireless communications possible (Chiang and Jakus, 1999:16).

A.5.2.3 Synergy ceramics

Within the epoch of advanced materials and as a result of the latest developments, Japan is taking further steps especially in R&D of advanced ceramics. Synergy ceramics are good examples to choose so as to shed light on the possible future of advanced ceramics. As a part of the Industrial Science and Technology Frontier Program (AIST, 2001) currently being conducted in Japan, synergy ceramics, which are produced by compositing structural and functional ceramics, are well on their way to be introduced to the market. The need for such a material has come out from the desire to be able to have efficient materials for severe conditions. Not only thermal resistance, high strength and corrosion resistance is sufficient properties any more, but reliability and endurance as well. Since it is very difficult to balance these properties by a structural control, AIST of Japan aims to improve the reliability of structural ceramics by use of functional ceramics. Therefore, the functional ceramics phase will be able to detect stress and cracks, foreknowing the possible destructions of composite ceramics. These advanced products may easily find use in energy, environment, aerospace and even in some traditional industries.

A.5.3 What is composite?

There is no widely accepted definition about what a composite material is. A very broad definition is the material made up of two distinct parts or constituents. In this case, even the metallic alloys and some polymeric materials may be named as composites. Moreover, the two distinctly different components are brought together with the aim of gaining advantageous characteristics from each of the component materials or to eliminate disadvantageous characteristics of each. Thus, there are requisites so as to call a material 'composite'. For instance, ceramics are brittle in nature but high temperature resistant materials. Being a component of a composite, their brittle character is healed. The whole composite turns out to have toughness, ductility and stiffness provided by the second component generally and high temperature strength provided by the ceramic component.

Ceramic composites basically have two types of structures. Ceramic component may either form the matrix part in which metal or polymer particulates, whiskers (discontinuous fibres) and fibres (continuous fibres) are embedded or it may itself form particulates, whiskers or fibres oriented within a metal, polymer or again ceramic matrix. Additionally, ceramic and metal powders, two different phases may commonly be processed by powder metallurgy (P/M) techniques to form a composite.

Ceramic composites offer an exciting opportunity to increase strength and toughness of pure ceramic materials, thereby opening a window of opportunity for wider and more reliable uses and applications. They have been composed of metal, plastic, carbon, glass or ceramic matrices reinforced with various types of fibres including carbon, silicon carbide, stainless steel, aramid under the commercial name Kevlar introduced by Du Pont in 1972 (Smith, 1993:595) and zirconia. Main ceramic-ceramic composites under development have been carbon-carbon composites with woven continuous fibre and other combinations mainly with silicon carbide fibres (Cartz, 1991:3) and whiskers. Alumina is the other extensively used type of fibre for CMCs. On the other hand, silica whisker addition to alumina can increase the fracture toughness of alumina ceramic matrix twofold (Smith, 1993:640). Partially stabilized zirconia (PSZ) is worth to be mentioned here as a special type of CMC. It receives a growing interest in the field of bioceramics originating from its tougher structure compared to other types of ceramics (Williams, 1994:7). Chaklader (1991:18) claims that the first true ceramic-ceramic composite for high technology applications, PSZ, was really discovered by Garvie in 1972, although King and Yavorsky in 1968 were the first to draw attention to the fact that PSZ had the capability to relieve stress by localized plastic deformation. Garvie et al. (1977 cited in Chaklader 1991:18) were the first to realize that thermal processing of PSZ can give both high strength and toughness and published a paper in *Nature* entitled "Ceramic Steel".

The first composite was produced some 50 years ago by associating glass and resin, such a material is as tough as glass but less fragile. Composites are first developed in the aerospace sector and find more applications in the chemical and transport industries, off-shore drilling and marina construction, recreation and sports, telecommunications, machine tools, building and housing uses, biotechnologies (Cohendet et al. 1988:25-6). The most widely used polymer matrix composite fibreglass has been in use since 1940s. Polymer matrix composites find use predominantly in the aerospace industry with defense applications. During the mid 1980s, aerospace applications of advanced polymer composites accounted for 60% of current sales, whilst 20% accounted for sports goods such as golf clubs and tennis rackets. Automobiles and industrial equipment come after as the third major user industries (OTA, 1986:6).

With the turn of the century, composites are being used in construction applications such as bridges and buildings, holding advantages of lightweight and increased durability. Optical fibres in today's communication industry are the major components of fast and advanced level of communication. Medical implants is another field of use. Their use in aerospace, automotive and sports industries is increasing with the development of new products with better and improve properties.

A.6 Production Techniques of Advanced Materials

There are two different types of core production methods for advanced materials depending on the product. For instance, bulk metal and ceramic parts and ceramic coatings are produced by totally dissimilar techniques and each of these comprises a number of slightly or considerably different technologies in a palette changing from the most traditional to the state-of-the-art one. More advanced products need more advanced production technologies.

A.6.1 Production Techniques of Advanced Material Parts: The P/M Process

The very common and traditional manufacturing method of bulk ceramic materials is based on processing ceramic powders by agglomeration, namely powder metallurgy (P/M). Because ceramics have very high melting points, they allow themselves to be produced at high temperatures still at solid form, at which metals would definitely be at liquid or even gas state. The most rewarding result of this characteristic of ceramics is giving opportunity for production of very small, intricate and reliable as well parts. The method is not only restricted to ceramic parts. Indeed, it has been developed for producing ferrous parts, i.e. high speed steels and passed to production of pure technical ceramics and ceramic composites with metal powders. The major difference in the use of P/M processes for metals and ceramics is that when shaping ceramics hot pressing methods are used and when shaping metal powders cold pressing methods are used. Figure A.4 shows the steps and alternative techniques in each step of P/M process.

A.6.1.1 Raw Material Specifications

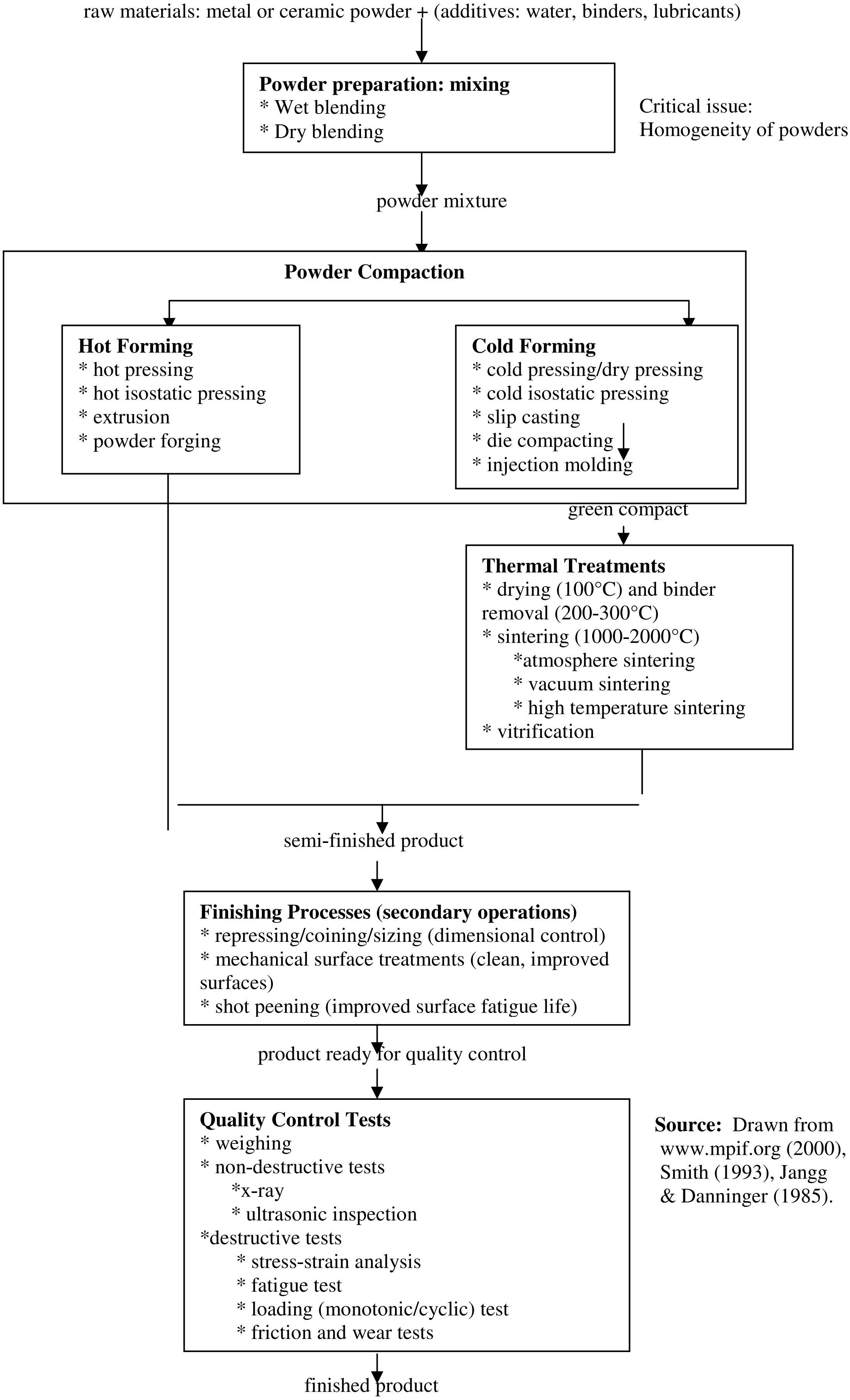
Preparation of powder and mixing it with consistent additives in consistent amounts is of crucial importance at the start of the P/M process. Because the whole chain of process influences the characteristics of end product, technological skills of the firm regarding raw material specifications play the first, but not the least, role in product improvement or innovation. As Smith (1993:536) also puts forward, for instance, traditional ceramics products, which do not have very critical properties such as common bricks, sewer pipe, the blending of ingredients with water is common practice. Contrastingly, for some other advance products raw materials are ground dry along with binders and other additives. To produce one type of high alumina insulator, the particulate raw materials are milled with water along with a wax binder to form slurry, which is subsequently spray-dried to form small spherical pellets.

A.6.1.2 Core Process

The core process is simply shaping the powders. It may be called either casting or pressing. The identifying feature of the step is the duration and degree of application of pressure and high temperature to the powder mixture in order to get semi-finished product from the green compact. Here, there is a palette of different alternatives of production technologies.

The more traditional technologies are cold-forming techniques in which the green compact product is subsequently subjected to thermal treatments, mainly sintering. Among the cold-forming techniques, ceramic injection molding is a recent technology capable of producing new range of components with high shape complexity, high density and high performance quality in a very cost efficient way (Sinter Metal Technologies, 2000). Sintering is the process by which small particles of material bonded together by solid-state diffusion. In ceramic manufacturing this thermal treatment results in the transformation of a porous compact into a dense, coherent product (Smith, 1995:541). In sintering, atomic diffusion takes place between the contacting surfaces of the particles so that they become chemically bonded together. As the process proceeds larger particles are formed at the expense of the smaller ones. As particles get larger, the porosity of the compacts decreases. With the attained equilibrium grain size of large particles, the high surface energy associated with the original individual small particles is replaced by the overall energy of sintered product (Smith, 1995:542-3). Therefore, sintering stage gives the ceramic product its main properties such as toughness, hardness and high strength to perform its structural functions in a reliable way by homogenizing the density and decreasing the system-wide energy of the product. The parameters substantial to be controlled are the level of pressure and temperature.

Figure A.4 Processing of metal and ceramic powders (Powder Metallurgy P/M technique)



Source: Drawn from www.mpif.org (2000), Smith (1993), Jangg & Danninger (1985).

Hot-forming techniques are developed as alternatives to cold-forming techniques followed by sintering and this contributed immensely to production in terms of time-saving measures. Especially hot isostatic pressing found a wide use in the industry, by which ceramic parts of high density and improved mechanical properties are produced. It is highly likely in the industry that firms even build up their own hot-forming technology by applying incremental improvements/changes to already well-known hot-forming techniques.

A.6.1.3 Secondary Operations

These are finishing operations predominantly applied to the surface of the product to give it the desired size and clean surface with an improved fatigue life.

A.6.1.4 Quality Control

Even though the process types are being improved during the last few decades so as to be able to produce more reliable ceramic products, as Chaklader (1991:17) also mentions the major obstacle in using ceramics especially for critical structural applications is their lack of reliability caused by uncontrolled flaw populations introduced during fabrication. 100 per cent flaw control is unfortunately not possible with today's production techniques, thereby arising a significant necessity for after-fabrication tests done on the product. Years ago, quality control tests were only of destructive type, where tests such as fracture, load-bearing, stress-strain analysis, friction were applied to selected specimens from the whole product and general conclusion were tried to be drawn for the whole product. With the introduction of sensitive non-destructive testing (NDT) which does not harm the product at all, nearly all the products may well be tested by ultrasonic, signal processing and/or x-ray techniques, promising the reliability for further use. However, application of NDT necessitates well-trained experts in the field. Especially the interpretation of test results is of considerable importance. At this point, the crucial importance of skilled labor and ongoing research in this field comes into account.

A.6.2 Production Techniques of Ceramic Coatings

A ceramic coating is a thin layer, usually of micrometer, nanometer scale, applied on a substrate of any material. The aim of coating is to endow the surface of the material with desired hardness, strength and toughness and protect it from corrosion as requested by the application field. There is growing interest for hardened surfaces by ceramic coatings in machine tool, automotive parts, aircraft gas turbines, manufacturing industries, biomedical sector and are expected to be used in land-based turbines and diesel engines. The principal reason for growing importance of this technology is that the destructive forces in most technological applications concentrate on the exterior of a component, thereby requiring surface properties that are intentionally different from the core. By utilizing surface engineering techniques, the composition or the mechanical property of the existing surface is altered or a different material is deposited to create a new surface (Sankaran, 1992:1). As emphasized in OTA (1986:14) report on new structural materials technologies, the coating approach offers several advantages for user industries. One is the ability optimize independently the properties of the surface for a given application. A second advantage is the ability to maintain close dimensional tolerances of the coated work piece, since very thin coatings (of the order of a few micrometers) are often sufficient for a given application. Further, cost savings are obtained by using expensive, exotic materials only for thin coatings and not for bulk materials. This can contribute to the conservation of strategically critical materials.

Finally, it is often cheaper to recoat a worn part than to replace it. Raw materials used for coating and surface treatment purposes are compounds of titanium, zirconium, chromium, boron, tungsten such as titanium nitride (TixNy or TiN), titanium carbo nitride (TiCxNy or TiCN), titanium aluminium nitride (TiAlxNy or TiAlN), chromium nitride (CrxNy or CrN), zirconium nitride (ZixNyor ZiN), titanium zirconium nitride (TiZrxNy or TiZrN), boron carbide (BC), tungsten carbide (WC). Boron carbide for example, as Olsson *et al*. (1988:453) have experimented, has many useful properties like high hardness, high temperature stability and promising wear resistance. Its use as a bulk material is very limited owing to the extreme brittleness. However, as a surface coating its disadvantages could be avoided. Moreover, Chemical Vapour Deposition appears to be the most promising method of fabrication for boron carbide coatings.

There are different commercial ways of producing coatings as shown in Figure A.5. The alternative methods of production are again totally dependent upon raw material specifications and the desired properties of the final product. Mechanical processes by work-hardening the surface, thermal treatments with laser or electron beam heating, diffusion treatments by carburising and nitriding, chemical treatments by etching and oxidation and traditional deposition techniques by physical or chemical ways are rather very conventional methods used since a long time and mainly applied on metal substrates as metal coatings. Since the last two decades, as well as those methods used by many firms for ceramic coatings, more advanced technologies such as thermal spraying, Physical Vapour Deposition (PVD), Chemical Vapour Deposition (CVD) and ion implantation are being used commercially to bring out more developed products.

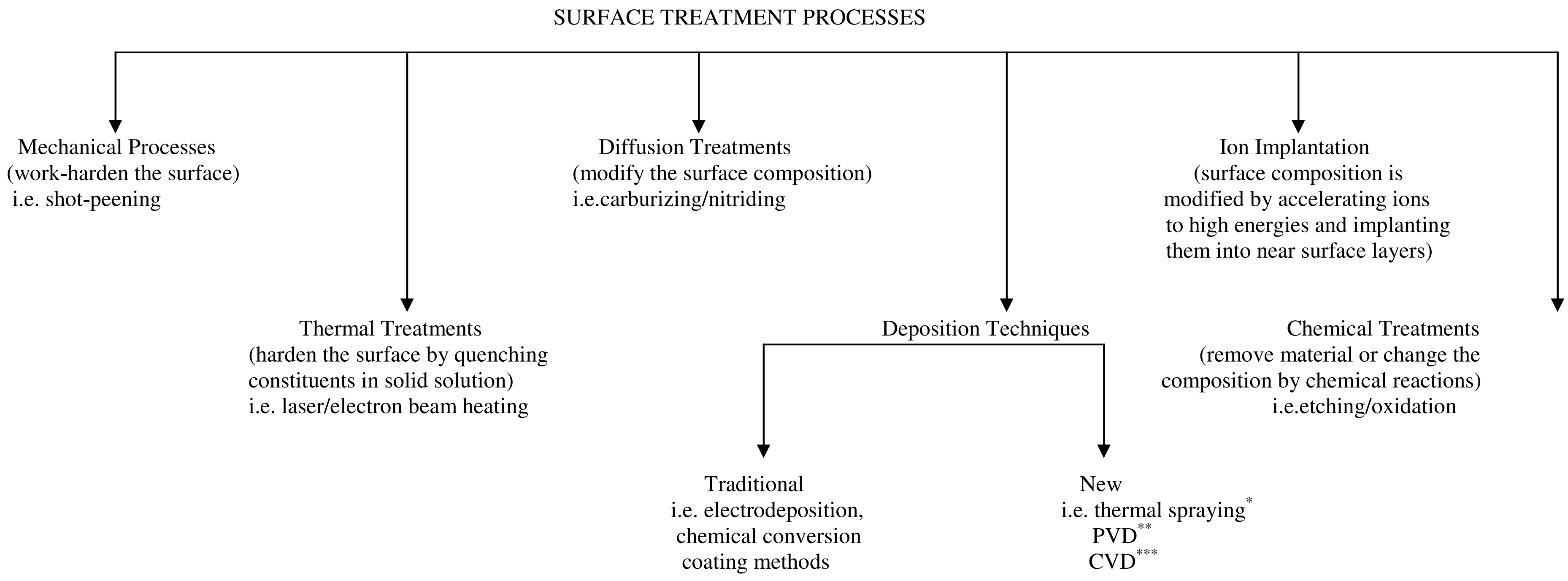
A.6.2.1 Thermal Spray Coating

Among the new deposition techniques thermal spray coating could well be taken as traditional. This is a way of spray coating of ceramics onto metals by arc, laser, plasma, and powder methods. A plasma or electric arc is used to melt a powder or wire source, and droplets of molten material are sprayed onto the surface to produce coating (Sankaran, 1992:1). Research is concentrated on the development of methods to measure chemical, elastic modulus, and thermal properties on a scale suitable for use in microstructural models of behaviour; the development of techniques to model thermomechanical behavior of thermal-barrier coatings to enable more reliable performance prediction and the development and refinement of more sensitive methods for accurate analysis of oxide phases and residual stresses which affect performance and durability of coatings (MSEL,1997).

A.6.2.2 Chemical Vapour Deposition (CVD)

The advantages of applying hard coatings on cemented carbide tools by CVD are well established and have led to commercial application for almost since the mid 1960s (Quinto et al. 1988:443). It has progressed from a laboratory curiosity to an indispensable tool of modern technology (Blocher, 1988:435). It is widely used for the formation of silicon carbide and silicon nitride through the chemical reaction of the vapour of the compound (Ichinose, 1987:30). It is a high temperature thermo chemical process operating at around 1000°C. In CVD processes the coating is deposited from a reactive gas atmosphere usually containing halogen chemical vapours. The chemicals used readily decompose at the high temperature in the reactor and recombine to form the desired coating on the hot parts. The high temperature nature of CVD effectively restricts its use to parts which are not affected by the high temperatures used, e.g. sintered carbide.

Figure A.5 Surface treatment processes/ Coating processes



* a plasma or electric arc is used to melt a powder or wire source, and droplets of molten material are sprayed onto the surface to produce coating.
** a vapor flux is created by a physical process such as evaporation, sputtering or laser ablation.
*** a reaction of vapor phase species with the sample surface produces a coating.

Source: Sankaran (1992)

Tools and components made from stainless steel and tool steels with loose tolerances are candidates for CVD coating (Multi-arc, 2001). During the last few years there is growing effort in the industry to develop low temperature CVD technology. This will make large area coatings possible on complex shaped parts and even on materials which contain zinc (Zn), tin (Sn), mercury (Hg) with low melting points and magnesium and will make cost effective production of advanced mobile and handheld display possible. Also stress caused by thermal expansion differentials between the coating and the substrate will be lowered (Blocher, 1988:436).

Applications of CVD range from the fabrication of microelectronic devices to the deposition of protective coatings. Largest applications are found in the microelectronics industry. However, wear resistant coatings for cutting tools and forming tools are running a close second. CVD generated optical fibres promise to supplant copper conductors in secure long-distance telephone communication and data transmission (Blocher, 1988:453). Though the technique mainly was developed as a means of coating, it has recently been used for the purification of high-purity metals, powder synthesis and thin film semiconductor manufacture as well (Ichinose, 1987:30).

CVD has its derivatives as widely developed such as layer flow CVD, plasma CVD, vacuum CVD, pyrolitic spray and liquid bed CVD (Ichinose, 1987:31).

A.6.2.3 Physical Vapour Deposition (PVD)

First commercial PVD tool coatings were introduced in 1979, initially on twist drills and taps but subsequently on a range of other tools. PVD tool coatings are dominated by TiN but other variants have subsequently been developed for specific applications (TiCN, TiAlN and CrN) (Bull, 2000). PVD is a vacuum chamber process where the metals are ionised by vaporisation and combined with the reactive gas to be deposited on the substrate. That is how a metal combined with a gas (oxygen, nitrogen or carbon) turns out to be a ceramic. There are a number of different PVD processes differing mainly in the type of evaporation technique used to produce metal vapour. The three main classes are sputtering and arc evaporation, which both use solid metal targets and electron beam evaporation, which is based on melting of the metal source (Korhonen et al. 1988:497). The main advantage of PVD is to be able to work at low temperatures, between 150°C - 500°C. Low temperature applicability is very important since ceramics can hardly tolerate internal strains arising from high temperature applications causing more brittleness.

This is a current and emerging technology and has a great tendency to incremental innovations. Thus, many firms innovate new processes as a derivative of PVD according to specifications of raw materials to be used and the final properties of the product. Cathodic Arc Physical Vapour Deposition, Enhanced Arc Physical Vapour Deposition, Unbalanced Magnetron Sputtering, Planer Magnetron Sputtering, etc. It is not surprising at all in this field that every new process creates a new product. Quinto et al. (1988:451) have reached to a conclusion in their experiment whereby titanium nitride is coated to carbide substrates by CVD and PVD for a basis of comparison that according to type of PVD process chosen, the microstructure, mechanical properties and metal cutting performance of the coating may be better or worse compared to that of CVD.

A.6.2.4 Ion Implantation
Ion implantation technique with metallurgical aims has been developed during the end of 1990s for use outside semiconductor industry and has become commercially successful with its low cost. Atoms of one or more elements speeded up in the form ions in a vacuum chamber are penetrated onto the surface of the substrate to a depth of 0,1mm-3mm with great energy. The process changes the crystal structure of the surface of ion implanted material around 50-100 microns. Nearly all the solid and gas state elements in the periodic table may be ion implanted. Consequently, modificated surfaces with ion implantation could reach to infinite combinations and the material may well be donated by precious mechanical and chemical properties such as resistance to stress, fatigue, wear, oxidation and corrosion. The main advantage of ion implantation to CVD and PVD lies at the process temperature, which is quite below 150°C, thereby supporting the resistance against brittleness especially for ceramics. It could well be applied to very intricate parts not changing the original size of the material, since implantation is in the size of microns.

A.6.2.5 Sol Gel Technology
Sol gel is a very recent, low temperature method using chemical precursors that produces ceramics and glasses with better purity and homogeneity than high temperature conventional processes and so is a competitive alternative to conventional methods. Sol gel has produced a wide range of compositions (mostly oxides) in various forms, including powders, fibres, coatings and thin films, monoliths and composites, and porous membranes. Organic/inorganic hybrids, where a gel (usually silica) is impregnated with polymers or organic dyes to provide specific properties, can be also made. The most attractive features of the sol gel process include the production of compositions not possible with conventional methods, along with the retention of the mixing level of the solution in the final product, often on the molecular scale (Business Communications Company, 1998).

The sol gel process is a versatile solution process for making ceramic and glass materials. In general, it involves the transition of a system from a liquid "sol" into a solid "gel" phase. Bell Laboratories (2001) invented a four-step process for application of sol gel process. The first step in forming a near-net shape body from sol gel is casting sol into a precision mole after being mixed with a proprietary combination of additives. After appropriate aging, the gel body is removed under water to reduce mechanical stress. The next step, drying, is efficiently removing water without cracking the body. The gel body has a fairly high water content, very small pore (and particle) size, and very low binder content, compared with conventional ceramics processes. The innovation that the Bell labs team perfected was to control the strength of the body so that early water removal (and most of the shrinkage) takes place when body is fairly elastic. The body then gains sufficient strength to overcome intrapore stress associated with removal of the pendular water near the end of drying. This challenge prevented the other research efforts from producing large sol gel bodies. In the purification step, dried tubes are loaded into a furnace and heated in various gases to remove organic compounds, water and impurities. It is the porous nature of the gel body that allows efficient removal of impurities to the level needed to produce world class level fibre optics less than 1 refractory particle (>1 micron diameter) in 30 kg glass. The purified body is consolidated to clear glass in chlorine, helium and oxygen. The final step in forming silica glass is sintering. Subsequent optical fibre fabrication would involve inserting an MCVD core rod inside the sol gel tube, collapsing and pulling optical fibre in a draw furnace.

Applying the sol gel process, it is possible to fabricate ceramic or glass materials in a wide variety of forms: ultra-fine or spherical shaped powders, thin film coatings, ceramic fibres especially fibreoptics, microporous inorganic membranes, monolithic ceramics and glasses, or extremely porous aerogel materials (Chemat Technology, 2001).The applications for sol gel-derived products are numerous. Electronic and optical applications are the fastest growing market segments from 1998 to 2003, at an average annual growth rate of 15%. High growth rates are expected also for chemical and biomedical applications of between 15% and 13% per year. By 2003, new market segments to emerge include biomedical applications (such as glucose sensors and drug therapy products) and high temperature applications (stationary gas turbine components) (Business Communications Company, 1998).

A.6.3 Production Techniques of Composites

Figure A.6 illustrates composite production techniques within a simple classification according to the matrix type.

It should be emphasized that toughening of pure ceramics through brittle fibres and whiskers depends very much on the interface between fibre and matrix. The rate of debonding of the fibre from the matrix to prevent a possible crack from propagating, the elastic moduli of both the fibre and the matrix are of critical importance (Cartz, 1991:6). Therefore, current research is concentrated on studies of matrix-fibre interfaces and coating of fibres targeting composites yielding more reliability and better performance.

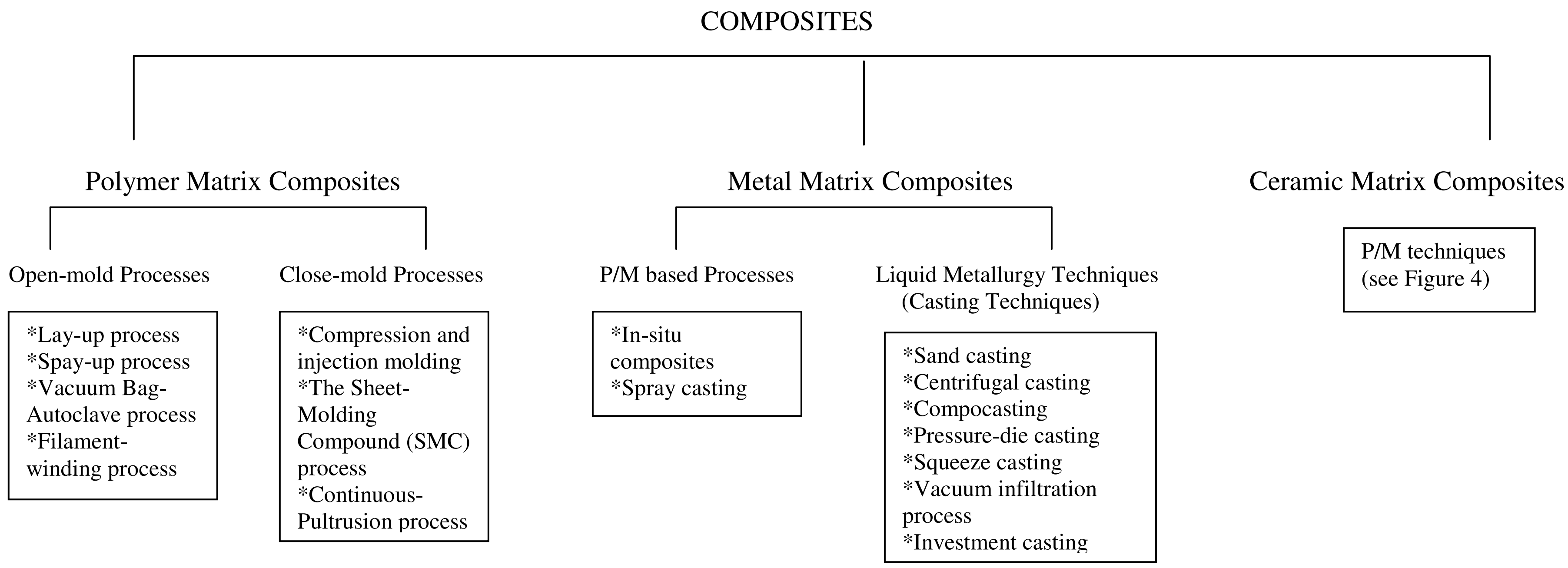
A.6.3.1 Ceramic Matrix Composite Production Techniques

Short fibre and particulate reinforced ceramic composites have advantage of being able to be fabricated by common ceramic process of P/M such as hot isostatic pressing, ceramic injection molding. On the other hand, for production of continuous fibre reinforced ceramics, fibres are woven into a mat and then often CVD is used to impregnate the matrix material into the fibrous mat (Smith, 1993:640).

A.6.3.2 Polymer Matrix Composite Production Techniques

Plastic matrix composites are produced by a number of either open-mold or close-mold processes. Some of the most important ones are listed in Figure 6. As described in detail in Smith (1993: 607-14) lay-up process and spray-up process both start with a gel coat as the reinforcement applied to the open mold and going on with either pouring by hand or spraying the resin over the reinforcement in the mold. Spray-up method offers greater complexity shapes and automation. As analyzed in the report of OTA (1986:6,43-62), most advanced PMCs are used in the aerospace industry. The laborious process lay up typically involves placement of sequential layers of polymer-impregnated fibre tapes on a mold surface, followed by heating under pressure to cure the lay-up into an integrated structure. Vacuum bag-autoclave process is suitable for high performance laminates of usually of fibre-reinforced epoxy systems to be used especially in aircraft and aerospace industries. The laminate is constructed on a shaped tool (e.g. in the shape of an aircraft wing section) with its plies and is vacuum-bagged with a vacuum being applied to remove entrapped air from the laminated part. Finally, the vacuum-bag enclosing the laminate and the tooling is put into an autoclave furnace for the final curing of the epoxy resin. Filament-winding process is used to produce high-strength hollow cylinders where the fibres are first soaked with plastic resin and then wound around a rotating mandrel. One of the mostly used methods is compression and injection molding, i.e. RTM- resin transfer moulding as used for CMCs except that the fibre reinforcement is mixed with the resin before processing. RTM is a low pressure moulding process, where a mixed resin and catalyst may also be injected into a closed mould containing a fibre pack or preform. When the resin has cured the mould can be opened and the finished component removed. SMC is one of the newer processes used mainly in the automotive industry, of highly automated continuous-flow type whereby chopped fibres and resin filler paste meet on a polyethylene film and form the composite. Continuous–pultrusion process is applied for production beams, channels and pipes and tubing.

Figure A.6 Composite production techniques



Source: Drawn from UNIDO (1990b), Smith (1993), OTA (1986.

A.6.3.3 Metal Matrix Composites Production Techniques

MMC production techniques are discussed in-depth in UNIDO (1990b:14-28). In-situ composites are produced with elemental powders where the process may be extrusion, drawing or rolling. Spray casting techniques are based on conventional gas atomization technology where a molten metal stream is impinged by a gas stream to create particulate. All the other liquid metallurgy techniques identified by casting represent one of the simplest methods of producing MMCs. The common feature of these techniques is the solidification of molten metal poured into a mold using patterns while adding the necessary reinforcements during the casting process.

P/M based methods are usually more costly compared to casting techniques and more complex shapes were said to be produced with the latter. However, production techniques are improving and today it is also possible to have intricate shapes with P/M methods. Moreover, in casting methods there is the problem of shrinkage during solidification, which requires excess material during casting and results in waste of material in the end, since the solidified excess part is thrown away. P/M techniques appear to be less costly in effective use of raw material.

GLOSSARY OF ADVANCED MATERIALS TERMINOLOGY

Sources: (Smith, 1993), (Ichinose, 1987), (Ceramic Bulletin, 2000), (Morrell, 1985)

Ceramic matrix composites (CMC): Composites having ceramic material as the matrix and metal, ceramic or polymer as the reinforcing material.

Cermet: Material consisting of a metal matrix with ceramic particles disseminated through it. Basically, it is a ceramic-metal composite, hard and resistant to high temperatures.

Composite material: A materials system composed of a mixture or combination of two or more micro- or macroconstituents that differ in form and chemical composition, essentially insoluble in each other (Smith, 1993) and have properties superior to those of the constituents alone.

Covalent bond: A primary or strong bond between the atoms of an element. Relatively large interatomic forces are created by the sharing of electrons to form a bond with a *localised direction* (Smith, 1993). Because covalent bonds are strong bonds, ceramics are able to resist high temperatures.

Dielectric: Substance or medium that can sustain an electric field; substance of very low electrical conductivity.

Firing (of a ceramic material): Heating a ceramic material to a high-enough temperature to cause a chemical bond to form between the particles (Smith, 1993).

Fracture toughness: Resistance to crack propagation/extension.

Ionic bond: A primary or strong bond between the atoms of an element. Relatively large interatomic forces are set up in this type of *nondirectional* bonding by an electron transfer from an atom to another to produce ions, which are bonded together (Smith, 1993). Because ionic bonds are strong bonds, ceramics are able to resist high temperatures.

Laminate: A product made by bonding sheets of generally two different materials together, usually with heat and pressure (Smith, 1993).

Materials Engineering: An engineering discipline, which is primarily concerned with use of fundamental and applied knowledge of materials so that they can be converted into products needed or desired by the society (Smith, 1993).

Materials Science: A scientific discipline, which is primarily concerned with the search for basic knowledge about internal structure, properties and processing of materials (Smith, 1993).

Machineability: Ability to be shaped, cut or removed (excess material) from (a workpiece) using a machine tool.

Metal matrix composites (MMC): Composites having a type of metal as the matrix and metal, ceramic or polymer as the reinforcing material.

Piezoelectricity: The production of electricity or electric polarity by applying mechanical stress.

Polymer matrix composites (PMC): Composites having polymeric material as the matrix and metal, ceramic or polymer as the reinforcing material.

Powder: Finely divided metallic, ceramic or polymeric solid, smaller than 1 mm in its maximum dimension. An important characteristic of it is its relatively high surface area to its volume.

Pyroelectricity: Temperature sensitivity characteristic.

Resonator: Timing devices suited for clock applications in camcorders, digital cameras, cellular telephones and other hand held and portable equipment (Ceramic Bulletin, 2000).

Sialon: It is a silicon nitride (Si_3N_4) system-oxide group material. It is formed as a compound of silicon nitride, alumina (Al_2O_3), silica (SiO_2) and aluminium nitride (AlN) when silicon nitride with silica added is sintered (Ichinose, 1987).

Sintering: A term used, in its pure sense, to imply the densification of a body at high temperatures in the absence of a liquid phase, i.e. by solid-state diffusion processes. However, the term is often used in situations where some liquid is also present to help redistribution of solid material by solution and reprecipitation.

Substrate: Any material, piece of material subjected to coating process.

Tribology: This is the study of friction, wear and lubrication of surfaces in relative motion. It is especially relevant to understanding the degradation of ceramic wear parts, bearings and the lubrication requirements of high-temperature ceramic engines (OTA, 1986:5).

Whisker: High-strength single crystals with length-to-diameter ratios of 10 or more. They are embedded in the matrix in a random way, not unidirectionally. The most common whisker material is silicon carbide due to its high strength.

APPENDIX B INTERVIEW QUESTIONS

Name of the firm:
Name and job title of the interviewee:
Date of the interview:

What kind of a firm is your firm?

independent	processor	SME
part of an enterprise group	raw material supplier	large firm
ltd. Company	potential user	
family-owned	consultant	
joint-stock company	engineering	
subsidiary	manufacturing	
parent company	representative	
	distributor	

1. History of the firm	2. The firm today
1. When was your firm founded?	
2. Why did you choose this special field to start the business? Since what time have you been producing advanced materials?	
3. How many employees were there in the firm at the beginning? Total ……….. Engineers …….. Researchers ……… Technical workers ………. Unskilled workers ……… Administrative staff ……….	4. How many employees do you have currently? Total ……. Engineers …….. Researchers ……… Technical workers ………. Unskilled workers ……… Administrative staff ……….
5. Which product(s) were you producing at the start of the business? Did you start the business with the aim of developing a particular product or process? Yes No Were you able to succeed? Yes No	6. What are you producing today?
7. Which below functions were you engaged in during the start of the business? Production R&D Strategic planning Distribution Marketing Training Consulting Other	8. Which below functions are you currently engaged in? Production R&D Strategic planning Distribution Marketing Training Consulting Other
9. Have you received any kind of financial support while starting the business? Yes No	10. Are you now receiving any kind of financial support, credits, export credits, etc.? Yes No

If yes, from where? What percentage of your initial expenses did it cover? Was the financial support given as a part of a project in order to develop a particular product or process? Yes No If yes, had the project achieved a successful result? What were the details of the project?	If yes, from where? Was the financial support given as a part of a project in order to develop a particular product or process? Yes No If no, for what reason?
11. What was the value of aggregate sales in TL or US$ at the end of the first year of the business?	12. What is the amount of aggregate sales of your firm in TL or US$ within the last year (before Feb.2001 crisis?)
13. Did you have the ultimate aim to export your products when starting the business? Yes No	14. Do you intend to increase the exports of your products in continuing the business? Yes No
15. When did you first start export activities? How did you build your links with the outside world? What percentage of the products was exported initially or sales gained from exports?	16. What is the export rate of your firm and your sales gained from exports for the last 3 years? To which countries do you mainly export your products?
17. Which were your original customers? Cutting tool Non-ferrous metal forming Ferrous metal forming Agricultural machinery Textile machinery Welding sector Automobile manufacturers Gas turbine manufacturers Aeroplane manufacturers Chemicals Oil industry Process engineering Nuclear industry Health sector (bio-medical applications) Other ………………….	18. From which sectors are your customers? Cutting tool Non-ferrous metal forming Ferrous metal forming Agricultural machinery Textile machinery Welding sector Automobile manufacturers Gas turbine manufacturers Aeroplane manufacturers Chemicals Oil Process engineering Nuclear industry Health sector (bio-medical applications) Other ………………….
19. How large was the original firm in terms of production at the end of the first year of the business?	20. What percentage has the firm grown in terms of production from the date of start till today? Was it a stable and increasing growth rate when considered annually? Yes No

3. Technology Acquisition

21. (Addressing the managers) What is your educational and academic background?

22. (Addressing the managers) What is your industrial background? Have you ever worked in another firm in the same field of activity?

23. How many researchers are employed in the firm (in full time equivalents)?
BS holders …….. MS holders ………. PhD holders …………

How many of them had work experience before started working in your company?
Abroad other domestic companies other research organizations other …………….

What are their disciplinary backgrounds (please give approximate proportions if known)?
metallurgy and materials science physics chemistry
mechanical engineering chemical engineering design engineering
other ……………….

24. Do you conduct research activities? Yes No
Is there an R&D unit (research laboratory) in your firm? Yes No
Where do you conduct your research activities?

25. Are your researchers subject to any kind of training from time to time? Yes No
What kinds of training?
for better use of the process technology
in order to be able to solve problems of the process technology at home
in order to be able to make contributions to already existing technology
to be able to better compete with rival firms by being simply innovative
on quality control and testing
on interpreting the quality control test results
other ………………………………………………………..

At home training or training abroad?
Approximately, how many hours per year?
How do you choose the researchers to subject to training?
Who/which organisation provides this activity?
informal on the job
formal in-house
university programmes
sector-based training initiatives
private consultants
other ………………………

26. Expenditure on R&D and design activities during the first activity year of your firm and the last year in TL or US$?

27.Does your firm conduct "design" activities as well, besides R&D? Yes No
If no, why?
We rely on customers' designs
We use other companies' designs
No qualified engineers in the research team to do design
Other …………………………………………..

If yes, which of the below contribute to your design activities?
influence of research institutes that we are in contact with
influence of foreign firms we are in contact with

influence of products/processes our engineers see in the fairs and exhibitions
influence of our personal contacts built in the conferences
influence of news about new products and processes in the magazines and journals of our field
only our own researchers knowledge in our own labs

28. Does your firm currently conduct and/or did it conduct a particular research project?
Yes No
If yes, what was/is it about?
If it has come to a result, was it successful or unsuccessful?
If unsuccessful, where do you put the blame?

29. Did you receive any financial support from the government for your research activities during the last five years? Yes No
Did you apply for any funds available? Yes No
What kind of fund were they and who was the sponsor(s)?

30. Do you think you need to produce new/improved products as a strategy to survive as a firm? Yes No
What are the specifications/distinguishing features of your new products within the last few years?
What are the objectives for aiming new products?
replace products being phased out
improve product quality
extend product range
open up new markets
increase market share
fulfilling regulations and standards
reduce environmental damage
other …………………………..

Do you think you need to produce new/improved processes as a strategy to survive as a firm?
Yes No
What are the specifications/distinguishing features of your new processes within the last few years?
What are the objectives for aiming new processes?
fulfilling regulations and standards
improve production flexibility
reduce labour costs
reduce material consumption
reduce energy consumption
improve product quality
extend product range
reduce environmental damage
other …………………………..

31. During the last five years have you introduced onto the market any technologically new or improved product? Yes No
Do they have any substitutes in the internal/world market? Yes No
If yes, can you give some information about the product(s)?

32. During the last five years have you introduced onto the market any technologically new or improved production process? Yes No

Do they have any substitutes in the internal/world market? Yes No
If yes, can you give some information about the process(es)?

33. Did you apply for at least one patent for a product/process during the last five years in any country? Yes No
Product/Process subject to patent?
Country applied?
Duration of patent?

34. Do you attempt to introduce your new products and processes onto the world market?
Yes No
If yes, how? Using which channels?

35. What are your internal sources for product/process development? Please rank.

R&D unit
design unit
production engineering staff
workers
marketing unit
management
other …………….

36. When you compare your firm's expertise in materials science aspects i.e. new product development oriented approaches, and engineering aspects i.e. effects of processing and design on ceramic properties, which one is better?
Why?

37. What are your existing technological strengths?
excellent research equipment
processing techniques developed in-house
quality and knowledge of the specific product you process
other …………………………………..
skilled engineers and research team
patent(s) you hold
R&D capability
excellent design activities

38. How do you learn about the new developments in products and processes (in the country and in the world) regarding your field?
from sources within the firm: staff go out of the firm i.e. one day or more a month to search for new information, in-house seminars, informal exchange of information, other ……………………………………..
from competitors. How? …………………………………
from customers. How? …………………………
from consultancy firms
from suppliers of equipment, materials, components or software
from universities or higher education institutes
from government or research institutes
from patent disclosures
from professional and scientific conferences, meetings
from journals
from our in-house library
from computer based information networks
from fairs and exhibitions

from membership of professional societies
from personal contacts: please elaborate …………………………
other …………………………………….

39. Does your firm provide any training to employees of other firms? Yes No
If yes, what kind of training?

40. Does your firm provide consultancy? Yes No
Mainly to which kind of firms?

41. What is your core production technology(ies)?
42. Peripheral technologies?

43. Levels of core technologies? Low-tech Medium-tech High-tech
How do you make the assessment?

Levels of peripheral technologies? Low-tech Medium-tech High-tech
How do you make the assessment?

44. What are the specifications of inputs and outputs in accordance with the core technology?(such as powder/coating specifications, powder/coating material preparation techniques, quality and the technological level of the final product,…)

Question	**Input** **Raw materials**	**Process technology**	**Output** **Processed material**
1. Core technology			
2. Peripheral tech.			
3. Tech. levels			
4. Specifications			

45. How did you acquire your core technology(ies)?
What have been, if any, the major changes in core technology?

	Core	Change 1	Change 2	Change 3
own technology	[]	[]	[]	[]
license/patent/trade-mark/franchise agr.	[]	[]	[]	[]
joint venture agreements	[]	[]	[]	[]
technical assistance/know-how	[]	[]	[]	[]
import of machinery	[]	[]	[]	[]
reverse-engineering	[]	[]	[]	[]
turn-key agreement	[]	[]	[]	[]
cooperation with foreign experts/consultants	[]	[]	[]	[]
cooperation with domestic experts/consultants	[]	[]	[]	[]
other ………………………….	[]	[]	[]	[]

A. IF YOU HAVE ACQUIRED YOUR TECHNOLOGY FROM OUTSIDE SOURCES:	B. IF IT WAS YOUR OWN TECHNOLOGY:
46a. From where did you acquire your technology?	46b. If your core technology is your own technology, which, if any, of the below

<table>
<tr><td>Country name …………
Firm name ……………..</td><td>factors were effective in its creation?
own skilled personnel trained abroad with academic degree from a foreign university
own skilled personnel trained in the country with academic degree from a national university
hiring foreign skilled labour
use of knowledge acquired from fairs and exhibitions
foreign journals, literature survey
national and international conferences
we are a representative of a foreign firm
other ……………………..</td></tr>
<tr><td>47a. How did you contact the supplier?
via a consultant firm abroad
via a consultant firm at home
internet search
journal ads
recommendation of a foreign firm in the field
recommendation of a domestic firm in the field
former personal contacts of the manager abroad
other ………………………………….</td><td>47b. How did you build the contacts for developing your technology?
via a consultant firm abroad
via a consultant firm at home
internet search
journal ads
recommendation of a foreign firm in the field
recommendation of a domestic firm in the field
former personal contacts of the manager abroad
other ………………………………….</td></tr>
<tr><td>48a. Did you conduct any research into the supplier firm?
No. Why? ………………………………
Yes. On our own. How?………………………
Yes. Via expert/consultant.</td><td>48b. What kind of relationship do you have with the firm that you are a representative of?</td></tr>
<tr><td>49a. What activities did you undertake while you were acquiring your technology?
Not any. Why? ………………………………
On our own. How? ……………………
Via expert/consultant. How? ………………</td><td>49b. Where can you place your own technology in the domestic market?
In the world market?
How do you know it?</td></tr>
<tr><td>50a. What was the level of acquired technology when considered for that time?
Low-tech Medium-tech High-tech</td><td>50b. What was the level of your own technology when considered for the time it was created?
Low-tech Medium-tech High-tech</td></tr>
<tr><td>51a.What criteria were significant in the choice of this particular technology?
Why did you choose this technology?
appropriateness of technology
price
state-of-the-art status of technology
application knowledge of your firm about the technology
after-sale services supplied by the supplier
appropriate to produce products needed in the internal market
appropriate to meet our export plans
we didn’t have any other choice, we received a tied-aid from ……..
other ……………………………………</td><td>51b. Why did you especially focus on creating this particular technology?
appropriateness of technology
would be less costly. Compared to what?
state-of-the-art status of technology
application knowledge of your firm about the technology
appropriate to produce products needed in the internal market
appropriate to meet our export plans
we didn’t have any other choice, we received a tied-aid from …….. to create this technology.
that was all we could do with our knowledge
other ……………………………………</td></tr>
</table>

52a. What type of extensions/points did your technology acquisition agreement include? guarantee of after-sale services. For how many years?……………. sending your technical personnel abroad to the supplier firm for training. How long?……… How many?………… technical personnel of supplier visiting your firm. How long? ….….. How many?………. knowledge transfer between the supplier and your firm as a result of any improvement on the technology originating from either side other ……………………………….	
53a. What kind of manpower training have you received from the supplier? for how to use the technology we acquired for process engineering for design activities other .... Was the training provided abroad or in-house? abroad in-house Do you think that your trained personnel contributed to firm's technological capabilities toward innovativeness as a result of this training? No. Yes. We had no problems in overcoming bottlenecks of the technology we acquired. Yes. We improved the technology we acquired a lot. Yes. We produce even more novel process technologies now. Yes. We even provide consultancy to some other firms. Other ……………………..	53b. Did you receive any manpower training during the creation period of your technology to complement your lacking knowledge ? If yes, from where? What kind of manpower training have you received ? Was the training provided abroad or in-house? abroad in-house Do you think that your trained personnel contributed to firm's technological capabilities toward innovativeness as a result of this training? How? No. Yes. We could learn about other agents ideas and use the knowledge at the start of our own work. Yes. By this way, we could be able to improve the technology we wanted to create a lot. Finally, we achieved more than what we have expected. Yes. We produce even more novel process technologies now. Yes. We even provide consultancy to some other firms. Other ……………………..
54a. Are you still in touch with your technology supplier? Yes No If not, why? We have no relation at all. They simply cheated us. Other ……………. If yes, what is the extent of relationship? We sometimes need help whenever we have a problem with the use of technology we acquired. We still acquire more developed technologies from	

them. We exchange ideas regarding the improvement of technology they supplied to us. We exchange ideas regarding the new process technologies we develop. We conduct joint projects, joint R&D activities. Other …………………….. Have you ever thought of changing your supplier? Yes No If yes, under what circumstances? At what stage of technology acquisition process?	
55a. What was the outcome and what contributions do you think your firm have made to the acquisition process?	

56. Have you ever had a problem originating from your process technology(ies) that you were not immediately able to overcome? Yes No
If yes, in what way did you solve the problem?

4. Firm interactions

A. Knowledge/information interactions with the domestic community	**B. Knowledge/information interactions with the foreign community**
AGENTS OF DOMESTIC COMMUNITY: * Domestic competitor firms * Domestic consultant firms * Industrial associations * National project sponsors * National universities * National research centres * Governmental units * Domestic raw material suppliers * Customers and end-user firms	AGENTS OF FOREIGN COMMUNITY: * Foreign competitor firms * Foreign consultant firms * Universities abroad * Foreign project supporters * Foreign research centres * Foreign raw material suppliers * Foreign customers and end-user firms
57a. Is your firm a member of any *national* association? Yes No Name of the association? ……………….	57b. Is your firm a member of any *international* association? Yes No Name of the association? ……………….

58. Is your firm located in a science park / technology center / technology corridor or at region where there are clusters of firms with the same functions? Yes No

If no, would you think that your location would help to improve your collaborative activities and flow of knowledge/information among the firms? Yes No
Why?

If yes, did you choose this site on purpose? Yes No
Why/why not?

What activities are being held within this community?
- building linkages with the outside world
- conducting common projects
- other ………………………………….

Do you think that your location helps to improve your collaborative activities and flow of knowledge/information among the firms? Yes No
How?

A. Knowledge/information interactions with the domestic community			**B. Knowledge/information interactions with the foreign community**		
Today	*Past*	**How? Why?**	**Today**	**Past**	**How? Why?**
59a. Is your firm engaged in any of the below activities with any of the above agents? research contract-out common project R&D collaboration joint product development joint process design joint venture joint production joint marketing/export promotion licensing other ………………	Have you had any of these activities in the past?		59b. Is your firm engaged in any of the below activities with any of the above agents? research contract-out common project R&D collaboration joint product development joint process design joint venture joint production joint marketing/export promotion licensing other ………………	Have you had any of these activities in the past?	
60a. Do you collaborate with any of the above agents while transferring/ developing your core production technology?	Were you still collaborating in the past?		60b. Do you collaborate with any of the above agents while transferring/ developing your core production technology?	Were you still collaborating in the past?	
61a. Do the above agent(s) contribute to any of your technological	If you have made any contributions to your existing		61b. Do the above agent(s) contribute to any of your technological	If you have made any contributions to your	

improvements?	core production technology, did any of the above play any role in this contribution?		improvements?	existing core production technology, did any of the above play any role in this contribution?	
62a. Which of the below identify your linkages with national universities? sponsoring final year students on projects sponsoring master's students sponsoring doctoral students employing university professors as consultants placing contracts with university research groups over several years uni. provides information, advice and instrumentation-based analysis/tests with advanced equipments and we provide raw materials, specimens of processed materials to them other ………………………….. In which fields below do you think that university has much more knowledge and expertise compared to your firm? making more use of theory, doesn't help us at all making more use of theory, which we benefit a lot combining theory and practise in an effective way developing processes/products how to use instruments interpreting test results generating projects more knowledge of research equipment other	Did you have the same activities in the past? Did you have the same idea in the past?		62b. Which of the below identify your linkages with foreign universities? sponsoring final year students on projects sponsoring master's students sponsoring doctoral students employing university professors as consultants placing contracts with university research groups over several years uni. provides information, advice and instrumentation-based analysis/tests with advanced equipments and we provide raw materials, specimens of processed materials to them other ………………………….. In which fields below do you think that university has much more knowledge and expertise compared to your firm? making more use of theory, doesn't help us at all making more use of theory, which we benefit a lot combining theory and practise in an effective way developing processes/products how to use instruments interpreting test results generating projects more knowledge of research equipment other	Did you have the same activities in the past? Did you have the same idea in the past?	
63a.How do you build and develop your	Did you have personal		63b.How do you build and develop your	Did you have personal	

informal personal contacts? Do you find these relations useful with regard to their contribution to firm technological capabilities? In what ways?	contacts in the past as well?		informal personal contacts? Do you find these relations useful with regard to their contribution to firm technological capabilities? In what ways?	contacts in the past as well?	
64a.Are TUBITAK, TIDEB, TTGV and TUBITAK MAM able to respond the demands of firms ? What services/what sort of collaboration would you expect from them?	Were they able to provide efficient outcomes in the past as well?				
65a. If you have no collaboration with any of the national sources, what are the reason(s)? risk of losing know-how risk of revealing cost structures or other proprietary information no suitable equivalent partner external solutions are too expensive lack of confidence in knowledge provided by external sources risk of losing skilled labour problems are solved better internally other…………………	If you had no collaboration in the past as well, what were the reasons? risk of losing know-how risk of revealing cost structures or other proprietary information no suitable equivalent partner external solutions are too expensive lack of confidence in knowledge provided by external sources risk of losing skilled labour problems are solved better internally other		65b. If you have no collaboration with any of the foreign sources, what are the reason(s)? risk of losing know-how risk of revealing cost structures or other proprietary information no suitable equivalent partner external solutions are too expensive lack of confidence in knowledge provided by external sources risk of losing skilled labour problems are solved better internally other…………………	If you had no collaboration in the past as well, what were the reasons? risk of losing know-how risk of revealing cost structures or other proprietary information no suitable equivalent partner external solutions are too expensive lack of confidence in knowledge provided by external sources risk of losing skilled labour problems are solved better internally other	
66a. Do you think that your performance is positively effected by cooperating with any of the above?	Did you think the same in the past as well?		66b. Do you think that your performance is positively effected by cooperating with any of the above?	Did you think the same in the past as well?	

APPENDIX C

Table C.1 Cross-tabulation of knowledge links by type of technology acquisition and period for all firms.

Type of technology acquisition * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Type of technology acquisition	arm's length activity	Count	16	49	61	126
		% within Type of technology acquisition	12.7%	38.9%	48.4%	100.0%
		% within Period	59.3%	34.8%	25.4%	30.9%
	firm-endogenous activity	Count	5	17	54	76
		% within Type of technology acquisition	6.6%	22.4%	71.1%	100.0%
		% within Period	18.5%	12.1%	22.5%	18.6%
	collaborative agreements	Count	4	58	118	180
		% within Type of technology acquisition	2.2%	32.2%	65.6%	100.0%
		% within Period	14.8%	41.1%	49.2%	44.1%
	FDI	Count	2	17	7	26
		% within Type of technology acquisition	7.7%	65.4%	26.9%	100.0%
		% within Period	7.4%	12.1%	2.9%	6.4%
Total		Count	27	141	240	408
		% within Type of technology acquisition	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.864[a]	6	.000
Likelihood Ratio	34.272	6	.000
Linear-by-Linear Association	3.824	1	.051
N of Valid Cases	408		

a. 1 cells (8.3%) have expected count less than 5. The minimum expected count is 1.72.

Table C.2 Cross-tabulation of knowledge links by type of technology acquisition and period for science-based technology firms.

Type of technology acquisition * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Type of technology acquisition	arm's length activity	Count	7	21	23	51
		% within Type of technology acquisition	13.7%	41.2%	45.1%	100.0%
		% within Period	63.6%	27.3%	17.8%	23.5%
	firm-endogenous activity	Count	2	5	34	41
		% within Type of technology acquisition	4.9%	12.2%	82.9%	100.0%
		% within Period	18.2%	6.5%	26.4%	18.9%
	collaborative agreements	Count	1	37	65	103
		% within Type of technology acquisition	1.0%	35.9%	63.1%	100.0%
		% within Period	9.1%	48.1%	50.4%	47.5%
	FDI	Count	1	14	7	22
		% within Type of technology acquisition	4.5%	63.6%	31.8%	100.0%
		% within Period	9.1%	18.2%	5.4%	10.1%
Total		Count	11	77	129	217
		% within Type of technology acquisition	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	31.244[a]	6	.000
Likelihood Ratio	32.044	6	.000
Linear-by-Linear Association	.868	1	.352
N of Valid Cases	217		

a. 3 cells (25.0%) have expected count less than 5. The minimum expected count is 1.12.

Table C.3 Cross-tabulation of knowledge links by type of technology acquisition and period for mature technology firms.

Type of technology acquisition * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Type of technology acquisition	arm's length activity	Count	9	28	38	75
		% within Type of technology acquisition	12.0%	37.3%	50.7%	100.0%
		% within Period	56.3%	43.8%	34.2%	39.3%
	firm-endogenous activity	Count	3	12	20	35
		% within Type of technology acquisition	8.6%	34.3%	57.1%	100.0%
		% within Period	18.8%	18.8%	18.0%	18.3%
	collaborative agreements	Count	3	21	53	77
		% within Type of technology acquisition	3.9%	27.3%	68.8%	100.0%
		% within Period	18.8%	32.8%	47.7%	40.3%
	FDI	Count	1	3	0	4
		% within Type of technology acquisition	25.0%	75.0%	.0%	100.0%
		% within Period	6.3%	4.7%	.0%	2.1%
Total		Count	16	64	111	191
		% within Type of technology acquisition	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.192[a]	6	.058
Likelihood Ratio	13.832	6	.032
Linear-by-Linear Association	2.799	1	.094
N of Valid Cases	191		

a. 4 cells (33.3%) have expected count less than 5. The minimum expected count is .34.

Table C.4 Cross-tabulation of knowledge links by percentage of researchers-engineers in total employees and period for all firms.

Percentage of researchers-engineers to total employees * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Percentage of researchers-engineers to total employees	more than 50%	Count	0	14	34	48
		% within Percentage of researchers-engineers to total employees	.0%	29.2%	70.8%	100.0%
		% within Period	.0%	9.9%	14.2%	11.8%
	less than 49%	Count	27	127	206	360
		% within Percentage of researchers-engineers to total employees	7.5%	35.3%	57.2%	100.0%
		% within Period	100.0%	90.1%	85.8%	88.2%
Total		Count	27	141	240	408
		% within Percentage of researchers-engineers to total employees	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.392[a]	2	.067
Likelihood Ratio	8.501	2	.014
Linear-by-Linear Association	4.931	1	.026
N of Valid Cases	408		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.18.

Table C.5 Cross-tabulation of knowledge links by percentage of researchers-engineers in total employees and period for science-based technology firms.

Percentage of researchers-engineers to total employees * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Percentage of researchers-engineers to total employees	more than 50%	Count	0	9	24	33
		% within Percentage of researchers-engineers to total employees	.0%	27.3%	72.7%	100.0%
		% within Period	.0%	11.7%	18.6%	15.2%
	less than 49%	Count	11	68	105	184
		% within Percentage of researchers-engineers to total employees	6.0%	37.0%	57.1%	100.0%
		% within Period	100.0%	88.3%	81.4%	84.8%
Total		Count	11	77	129	217
		% within Percentage of researchers-engineers to total employees	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.867[a]	2	.145
Likelihood Ratio	5.513	2	.064
Linear-by-Linear Association	3.732	1	.053
N of Valid Cases	217		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.67.

Table C.6 Cross-tabulation of knowledge links by percentage of researchers-engineers in total employees and period for mature technology firms.

Percentage of researchers-engineers to total employees * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Percentage of researchers-engineers to total employees	more than 50%	Count	0	5	10	15
		% within Percentage of researchers-engineers to total employees	.0%	33.3%	66.7%	100.0%
		% within Period	.0%	7.8%	9.0%	7.9%
	less than 49%	Count	16	59	101	176
		% within Percentage of researchers-engineers to total employees	9.1%	33.5%	57.4%	100.0%
		% within Period	100.0%	92.2%	91.0%	92.1%
Total		Count	16	64	111	191
		% within Percentage of researchers-engineers to total employees	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.569[a]	2	.456
Likelihood Ratio	2.814	2	.245
Linear-by-Linear Association	1.111	1	.292
N of Valid Cases	191		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.26.

Table C.7 Cross-tabulation of knowledge links by manager specifications related to academic experiences and period for all firms.

Manager specifications related to education & academic experience * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Manager specifications related to education & academic experience	foreign university degree	Count	4	26	62	92
		% within Manager specifications related to education & academic experience	4.3%	28.3%	67.4%	100.0%
		% within Period	14.8%	18.4%	25.8%	22.5%
	national university degree	Count	22	98	172	292
		% within Manager specifications related to education & academic experience	7.5%	33.6%	58.9%	100.0%
		% within Period	81.5%	69.5%	71.7%	71.6%
	no degree	Count	1	17	6	24
		% within Manager specifications related to education & academic experience	4.2%	70.8%	25.0%	100.0%
		% within Period	3.7%	12.1%	2.5%	5.9%
Total		Count	27	141	240	408
		% within Manager specifications related to education & academic experience	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	17.399[a]	4	.002
Likelihood Ratio	16.686	4	.002
Linear-by-Linear Association	7.643	1	.006
N of Valid Cases	408		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 1.59.

Table C.8 Cross-tabulation of knowledge links by manager specifications related to academic experiences and period for science-based technology firms.

Manager specifications related to education & academic experience * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Manager specifications related to education & academic experience	foreign university degree	Count	0	26	45	71
		% within Manager specifications related to education & academic experience	.0%	36.6%	63.4%	100.0%
		% within Period	.0%	33.8%	34.9%	32.7%
	national university degree	Count	11	34	78	123
		% within Manager specifications related to education & academic experience	8.9%	27.6%	63.4%	100.0%
		% within Period	100.0%	44.2%	60.5%	56.7%
	no degree	Count	0	17	6	23
		% within Manager specifications related to education & academic experience	.0%	73.9%	26.1%	100.0%
		% within Period	.0%	22.1%	4.7%	10.6%
Total		Count	11	77	129	217
		% within Manager specifications related to education & academic experience	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	24.952[a]	4	.000
Likelihood Ratio	28.057	4	.000
Linear-by-Linear Association	5.683	1	.017
N of Valid Cases	217		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 1.17.

Table C.9 Cross-tabulation of knowledge links by manager specifications related to academic experiences and period for mature technology firms.

Manager specifications related to education & academic experience * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Manager specifications related to education & academic experience	foreign university degree	Count	4	0	17	21
		% within Manager specifications related to education & academic experience	19.0%	.0%	81.0%	100.0%
		% within Period	25.0%	.0%	15.3%	11.0%
	national university degree	Count	11	64	94	169
		% within Manager specifications related to education & academic experience	6.5%	37.9%	55.6%	100.0%
		% within Period	68.8%	100.0%	84.7%	88.5%
	no degree	Count	1	0	0	1
		% within Manager specifications related to education & academic experience	100.0%	.0%	.0%	100.0%
		% within Period	6.3%	.0%	.0%	.5%
Total		Count	16	64	111	191
		% within Manager specifications related to education & academic experience	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	24.558[a]	4	.000
Likelihood Ratio	24.667	4	.000
Linear-by-Linear Association	1.965	1	.161
N of Valid Cases	191		

a. 4 cells (44.4%) have expected count less than 5. The minimum expected count is .08.

Table C.10 Cross-tabulation of knowledge links by manager specifications related to industrial experiences and period for all firms.

Manager specifications related to industrial experiences * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Manager specifications related to industrial experiences	workexperience at a firm abroad	Count	4	12	30	46
		% within Manager specifications related to industrial experiences	8.7%	26.1%	65.2%	100.0%
		% within Period	14.8%	8.5%	12.5%	11.3%
	workexperience at a domestic firm	Count	23	125	210	358
		% within Manager specifications related to industrial experiences	6.4%	34.9%	58.7%	100.0%
		% within Period	85.2%	88.7%	87.5%	87.7%
	no experience	Count	0	4	0	4
		% within Manager specifications related to industrial experiences	.0%	100.0%	.0%	100.0%
		% within Period	.0%	2.8%	.0%	1.0%
Total		Count	27	141	240	408
		% within Manager specifications related to industrial experiences	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.185[a]	4	.057
Likelihood Ratio	10.162	4	.038
Linear-by-Linear Association	.949	1	.330
N of Valid Cases	408		

a. 4 cells (44.4%) have expected count less than 5. The minimum expected count is .26.

Table C.11 Cross-tabulation of knowledge links by manager specifications related to industrial experiences and period for science-based technology firms.

Manager specifications related to industrial experiences * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Manager specifications related to industrial experiences	workexperience at a firm abroad	Count	0	12	30	42
		% within Manager specifications related to industrial experiences	.0%	28.6%	71.4%	100.0%
		% within Period	.0%	15.6%	23.3%	19.4%
	workexperience at a domestic firm	Count	11	61	99	171
		% within Manager specifications related to industrial experiences	6.4%	35.7%	57.9%	100.0%
		% within Period	100.0%	79.2%	76.7%	78.8%
	no experience	Count	0	4	0	4
		% within Manager specifications related to industrial experiences	.0%	100.0%	.0%	100.0%
		% within Period	.0%	5.2%	.0%	1.8%
Total		Count	11	77	129	217
		% within Manager specifications related to industrial experiences	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.680[a]	4	.020
Likelihood Ratio	14.755	4	.005
Linear-by-Linear Association	6.310	1	.012
N of Valid Cases	217		

a. 4 cells (44.4%) have expected count less than 5. The minimum expected count is .20.

Table C.12 Cross-tabulation of knowledge links by manager specifications related to industrial experiences and period for mature technology firms.

Manager specifications related to industrial experiences * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Manager specifications related to industrial experiences	work experience at a firm abroad	Count	4	0	0	4
		% within Manager specifications related to industrial experiences	100.0%	.0%	.0%	100.0%
		% within Period	25.0%	.0%	.0%	2.1%
	work experience at a domestic firm	Count	12	64	111	187
		% within Manager specifications related to industrial experiences	6.4%	34.2%	59.4%	100.0%
		% within Period	75.0%	100.0%	100.0%	97.9%
Total		Count	16	64	111	191
		% within Manager specifications related to industrial experiences	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	44.686[a]	2	.000
Likelihood Ratio	20.849	2	.000
Linear-by-Linear Association	21.825	1	.000
N of Valid Cases	191		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is .34.

Table C.13 Cross-tabulation of knowledge links by search into contributor and period for all firms.

Search into contributor * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Search into contributor	experience-based research	Count	20	119	197	336
		% within Search into contributor	6.0%	35.4%	58.6%	100.0%
		% within Period	74.1%	84.4%	82.1%	82.4%
	none or simple research	Count	7	22	43	72
		% within Search into contributor	9.7%	30.6%	59.7%	100.0%
		% within Period	25.9%	15.6%	17.9%	17.6%
Total		Count	27	141	240	408
		% within Search into contributor	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.691[a]	2	.429
Likelihood Ratio	1.578	2	.454
Linear-by-Linear Association	.111	1	.739
N of Valid Cases	408		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 4.76.

Table C.14 Cross-tabulation of knowledge links by search into contributor and period for science-based technology firms.

Search into contributor * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Search into contributor	experience-based research	Count	6	66	108	180
		% within Search into contributor	3.3%	36.7%	60.0%	100.0%
		% within Period	54.5%	85.7%	83.7%	82.9%
	none or simple research	Count	5	11	21	37
		% within Search into contributor	13.5%	29.7%	56.8%	100.0%
		% within Period	45.5%	14.3%	16.3%	17.1%
Total		Count	11	77	129	217
		% within Search into contributor	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.745[a]	2	.034
Likelihood Ratio	5.266	2	.072
Linear-by-Linear Association	1.575	1	.209
N of Valid Cases	217		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.88.

Table C.15 Cross-tabulation of knowledge links by search into contributor and period for mature technology firms.

Search into contributor * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Search into contributor	experience-based research	Count	14	53	89	156
		% within Search into contributor	9.0%	34.0%	57.1%	100.0%
		% within Period	87.5%	82.8%	80.2%	81.7%
	none or simple research	Count	2	11	22	35
		% within Search into contributor	5.7%	31.4%	62.9%	100.0%
		% within Period	12.5%	17.2%	19.8%	18.3%
Total		Count	16	64	111	191
		% within Search into contributor	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.584[a]	2	.747
Likelihood Ratio	.617	2	.734
Linear-by-Linear Association	.560	1	.454
N of Valid Cases	191		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 2.93.

Table C.16 Cross-tabulation of knowledge links by search into technology and period for all firms.

Search into technology received from contributor * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Search into technology received from contributor	knowledge-based research	Count	23	132	223	378
		% within Search into technology received from contributor	6.1%	34.9%	59.0%	100.0%
		% within Period	85.2%	93.6%	92.9%	92.6%
	none or simple research	Count	4	9	17	30
		% within Search into technology received from contributor	13.3%	30.0%	56.7%	100.0%
		% within Period	14.8%	6.4%	7.1%	7.4%
Total		Count	27	141	240	408
		% within Search into technology received from contributor	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.427[a]	2	.297
Likelihood Ratio	1.971	2	.373
Linear-by-Linear Association	.666	1	.414
N of Valid Cases	408		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.99.

Table C.17 Cross-tabulation of knowledge links by search into technology and period for science-based technology firms.

Search into technology received from contributor * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Search into technology received from contributor	knowledge-based research	Count	9	74	125	208
		% within Search into technology received from contributor	4.3%	35.6%	60.1%	100.0%
		% within Period	81.8%	96.1%	96.9%	95.9%
	none or simple research	Count	2	3	4	9
		% within Search into technology received from contributor	22.2%	33.3%	44.4%	100.0%
		% within Period	18.2%	3.9%	3.1%	4.1%
Total		Count	11	77	129	217
		% within Search into technology received from contributor	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.818[a]	2	.055
Likelihood Ratio	3.463	2	.177
Linear-by-Linear Association	2.765	1	.096
N of Valid Cases	217		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is .46.

Table C.18 Cross-tabulation of knowledge links by search into technology and period for mature technology firms.

Search into technology received from contributor * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Search into technology received from contributor	knowledge-based research	Count	14	58	98	170
		% within Search into technology received from contributor	8.2%	34.1%	57.6%	100.0%
		% within Period	87.5%	90.6%	88.3%	89.0%
	none or simple research	Count	2	6	13	21
		% within Search into technology received from contributor	9.5%	28.6%	61.9%	100.0%
		% within Period	12.5%	9.4%	11.7%	11.0%
Total		Count	16	64	111	191
		% within Search into technology received from contributor	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.267[a]	2	.875
Likelihood Ratio	.272	2	.873
Linear-by-Linear Association	.039	1	.843
N of Valid Cases	191		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.76.

Table C.19 Cross-tabulation of knowledge links by R&D activities and period for all firms.

R&D activities * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
R&D activities	primary	Count	0	1	28	29
		% within R&D activities	.0%	3.4%	96.6%	100.0%
		% within Period	.0%	.7%	11.7%	7.1%
	active	Count	0	7	34	41
		% within R&D activities	.0%	17.1%	82.9%	100.0%
		% within Period	.0%	5.0%	14.2%	10.0%
	none	Count	27	133	178	338
		% within R&D activities	8.0%	39.3%	52.7%	100.0%
		% within Period	100.0%	94.3%	74.2%	82.8%
Total		Count	27	141	240	408
		% within R&D activities	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	32.833[a]	4	.000
Likelihood Ratio	41.928	4	.000
Linear-by-Linear Association	28.841	1	.000
N of Valid Cases	408		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 1.92.

Table C.20 Cross-tabulation of knowledge links by R&D activities and period for science-based technology firms.

R&D activities * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
R&D activities	primary	Count	0	1	25	26
		% within R&D activities	.0%	3.8%	96.2%	100.0%
		% within Period	.0%	1.3%	19.4%	12.0%
	active	Count	0	6	22	28
		% within R&D activities	.0%	21.4%	78.6%	100.0%
		% within Period	.0%	7.8%	17.1%	12.9%
	none	Count	11	70	82	163
		% within R&D activities	6.7%	42.9%	50.3%	100.0%
		% within Period	100.0%	90.9%	63.6%	75.1%
Total		Count	11	77	129	217
		% within R&D activities	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	25.001[a]	4	.000
Likelihood Ratio	31.453	4	.000
Linear-by-Linear Association	22.566	1	.000
N of Valid Cases	217		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 1.32.

Table C.21 Cross-tabulation of knowledge links by R&D activities and period for mature technology firms.

R&D activities * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
R&D activities	primary	Count	0	0	3	3
		% within R&D activities	.0%	.0%	100.0%	100.0%
		% within Period	.0%	.0%	2.7%	1.6%
	active	Count	0	1	12	13
		% within R&D activities	.0%	7.7%	92.3%	100.0%
		% within Period	.0%	1.6%	10.8%	6.8%
	none	Count	16	63	96	175
		% within R&D activities	9.1%	36.0%	54.9%	100.0%
		% within Period	100.0%	98.4%	86.5%	91.6%
Total		Count	16	64	111	191
		% within R&D activities	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.219[a]	4	.056
Likelihood Ratio	12.180	4	.016
Linear-by-Linear Association	7.536	1	.006
N of Valid Cases	191		

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is .25.

Table C.22 Cross-tabulation of knowledge links by design activities and period for all firms.

Design activities * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Design activities	non-trivial	Count	4	14	97	115
		% within Design activities	3.5%	12.2%	84.3%	100.0%
		% within Period	14.8%	9.9%	40.4%	28.2%
	trivial and none	Count	23	127	143	293
		% within Design activities	7.8%	43.3%	48.8%	100.0%
		% within Period	85.2%	90.1%	59.6%	71.8%
Total		Count	27	141	240	408
		% within Design activities	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	43.340[a]	2	.000
Likelihood Ratio	47.554	2	.000
Linear-by-Linear Association	34.370	1	.000
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.61.

Table C.23 Cross-tabulation of knowledge links by design activities and period for science-based technology firms.

Design activities * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Design activities	non-trivial	Count	4	7	57	68
		% within Design activities	5.9%	10.3%	83.8%	100.0%
		% within Period	36.4%	9.1%	44.2%	31.3%
	trivial and none	Count	7	70	72	149
		% within Design activities	4.7%	47.0%	48.3%	100.0%
		% within Period	63.6%	90.9%	55.8%	68.7%
Total		Count	11	77	129	217
		% within Design activities	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.738[a]	2	.000
Likelihood Ratio	31.428	2	.000
Linear-by-Linear Association	15.662	1	.000
N of Valid Cases	217		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.45.

Table C.24 Cross-tabulation of knowledge links by design activities and period for mature technology firms.

Design activities * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Design activities	non-trivial	Count	0	7	40	47
		% within Design activities	.0%	14.9%	85.1%	100.0%
		% within Period	.0%	10.9%	36.0%	24.6%
	trivial and none	Count	16	57	71	144
		% within Design activities	11.1%	39.6%	49.3%	100.0%
		% within Period	100.0%	89.1%	64.0%	75.4%
Total		Count	16	64	111	191
		% within Design activities	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.483[a]	2	.000
Likelihood Ratio	23.857	2	.000
Linear-by-Linear Association	18.579	1	.000
N of Valid Cases	191		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.94.

Table C.25 Cross-tabulation of knowledge links by increment in capability and period for all firms.

Increment in capability * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Increment in capability	operational capability or no capability acquired	Count	26	94	96	216
		% within Increment in capability	12.0%	43.5%	44.4%	100.0%
		% within Period	96.3%	66.7%	40.0%	52.9%
	improvement of process or product technology	Count	1	38	55	94
		% within Increment in capability	1.1%	40.4%	58.5%	100.0%
		% within Period	3.7%	27.0%	22.9%	23.0%
	development of product or process technology	Count	0	9	89	98
		% within Increment in capability	.0%	9.2%	90.8%	100.0%
		% within Period	.0%	6.4%	37.1%	24.0%
Total		Count	27	141	240	408
		% within Increment in capability	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	69.312[a]	4	.000
Likelihood Ratio	81.754	4	.000
Linear-by-Linear Association	60.641	1	.000
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.22.

Table C.26 Cross-tabulation of knowledge links by increment in capability and period for science-based technology firms.

Increment in capability * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Increment in capability	operational capability or no capability acquired	Count	11	47	43	101
		% within Increment in capability	10.9%	46.5%	42.6%	100.0%
		% within Period	100.0%	61.0%	33.3%	46.5%
	improvement of process or product technology	Count	0	21	30	51
		% within Increment in capability	.0%	41.2%	58.8%	100.0%
		% within Period	.0%	27.3%	23.3%	23.5%
	development of product or process technology	Count	0	9	56	65
		% within Increment in capability	.0%	13.8%	86.2%	100.0%
		% within Period	.0%	11.7%	43.4%	30.0%
Total		Count	11	77	129	217
		% within Increment in capability	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	37.791[a]	4	.000
Likelihood Ratio	43.835	4	.000
Linear-by-Linear Association	33.798	1	.000
N of Valid Cases	217		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.59.

Table C.27 Cross-tabulation of knowledge links by increment in capability and period for mature technology firms.

Increment in capability * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Increment in capability	operational capability or no capability acquired	Count	15	47	53	115
		% within Increment in capability	13.0%	40.9%	46.1%	100.0%
		% within Period	93.8%	73.4%	47.7%	60.2%
	improvement of process or product technology	Count	1	17	25	43
		% within Increment in capability	2.3%	39.5%	58.1%	100.0%
		% within Period	6.3%	26.6%	22.5%	22.5%
	development of product or process technology	Count	0	0	33	33
		% within Increment in capability	.0%	.0%	100.0%	100.0%
		% within Period	.0%	.0%	29.7%	17.3%
Total		Count	16	64	111	191
		% within Increment in capability	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.842[a]	4	.000
Likelihood Ratio	46.275	4	.000
Linear-by-Linear Association	27.049	1	.000
N of Valid Cases	191		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.76.

Table C.28 Cross-tabulation of knowledge links by type of technology acquisition and increment in capability for all firms.

Type of technology acquisition * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of process or product technology	development of product or process technology	Total
Type of technology acquisition	arm's length activity	Count	110	14	4	128
		% within Type of technology acquisition	85.9%	10.9%	3.1%	100.0%
		% within Increment in capability	50.9%	14.9%	4.1%	31.4%
	firm-endogenous activity	Count	12	22	42	76
		% within Type of technology acquisition	15.8%	28.9%	55.3%	100.0%
		% within Increment in capability	5.6%	23.4%	42.9%	18.6%
	collaborative agreements	Count	78	51	49	178
		% within Type of technology acquisition	43.8%	28.7%	27.5%	100.0%
		% within Increment in capability	36.1%	54.3%	50.0%	43.6%
	FDI	Count	16	7	3	26
		% within Type of technology acquisition	61.5%	26.9%	11.5%	100.0%
		% within Increment in capability	7.4%	7.4%	3.1%	6.4%
Total		Count	216	94	98	408
		% within Type of technology acquisition	52.9%	23.0%	24.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	117.940[a]	6	.000
Likelihood Ratio	129.099	6	.000
Linear-by-Linear Association	24.509	1	.000
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.99.

Table C.29 Cross-tabulation of knowledge links by type of technology acquisition and increment in capability for science-based technology firms.

Type of technology acquisition * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Type of technology acquisition	arm's length activity	Count	41	9	1	51
		% within Type of technology acquisition	80.4%	17.6%	2.0%	100.0%
		% within Increment in capability	40.6%	17.6%	1.5%	23.5%
	firm-endogenous activity	Count	3	6	32	41
		% within Type of technology acquisition	7.3%	14.6%	78.0%	100.0%
		% within Increment in capability	3.0%	11.8%	49.2%	18.9%
	collaborative agreements	Count	44	30	29	103
		% within Type of technology acquisition	42.7%	29.1%	28.2%	100.0%
		% within Increment in capability	43.6%	58.8%	44.6%	47.5%
	FDI	Count	13	6	3	22
		% within Type of technology acquisition	59.1%	27.3%	13.6%	100.0%
		% within Increment in capability	12.9%	11.8%	4.6%	10.1%
Total		Count	101	51	65	217
		% within Type of technology acquisition	46.5%	23.5%	30.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	77.882[a]	6	.000
Likelihood Ratio	83.713	6	.000
Linear-by-Linear Association	2.962	1	.085
N of Valid Cases	217		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.17.

Table C.30 Cross-tabulation of knowledge links by type of technology acquisition and increment in capability for mature technology firms.

Type of technology acquisition * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of process or product technology	development of product or process technology	Total
Type of technology acquisition	arm's length activity	Count	69	5	3	77
		% within Type of technology acquisition	89.6%	6.5%	3.9%	100.0%
		% within Increment in capability	60.0%	11.6%	9.1%	40.3%
	firm-endogenous activity	Count	9	16	10	35
		% within Type of technology acquisition	25.7%	45.7%	28.6%	100.0%
		% within Increment in capability	7.8%	37.2%	30.3%	18.3%
	collaborative agreements	Count	34	21	20	75
		% within Type of technology acquisition	45.3%	28.0%	26.7%	100.0%
		% within Increment in capability	29.6%	48.8%	60.6%	39.3%
	FDI	Count	3	1	0	4
		% within Type of technology acquisition	75.0%	25.0%	.0%	100.0%
		% within Increment in capability	2.6%	2.3%	.0%	2.1%
Total		Count	115	43	33	191
		% within Type of technology acquisition	60.2%	22.5%	17.3%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	54.116[a]	6	.000
Likelihood Ratio	59.668	6	.000
Linear-by-Linear Association	23.685	1	.000
N of Valid Cases	191		

a. 3 cells (25.0%) have expected count less than 5. The minimum expected count is .69.

Table C.31 Cross-tabulation of knowledge links by percentage of researchers/engineers in the firm and increment in capability for all firms.

Percentage of researchers-engineers to total employees * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Percentage of researchers-engineers to total employees	more than 50%	Count	19	11	18	48
		% within Percentage of researchers-engineers to total employees	39.6%	22.9%	37.5%	100.0%
		% within Increment in capability	8.8%	11.7%	18.4%	11.8%
	less than 49%	Count	197	83	80	360
		% within Percentage of researchers-engineers to total employees	54.7%	23.1%	22.2%	100.0%
		% within Increment in capability	91.2%	88.3%	81.6%	88.2%
Total		Count	216	94	98	408
		% within Percentage of researchers-engineers to total employees	52.9%	23.0%	24.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.949[a]	2	.051
Likelihood Ratio	5.580	2	.061
Linear-by-Linear Association	5.698	1	.017
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 11.06.

Table C.32 Cross-tabulation of knowledge links by percentage of researchers/engineers in the firm and increment in capability for science-based technology firms.

Percentage of researchers-engineers to total employees * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Percentage of researchers-engineers to total employees	more than 50%	Count	15	5	13	33
		% within Percentage of researchers-engineers to total employees	45.5%	15.2%	39.4%	100.0%
		% within Increment in capability	14.9%	9.8%	20.0%	15.2%
	less than 49%	Count	86	46	52	184
		% within Percentage of researchers-engineers to total employees	46.7%	25.0%	28.3%	100.0%
		% within Increment in capability	85.1%	90.2%	80.0%	84.8%
Total		Count	101	51	65	217
		% within Percentage of researchers-engineers to total employees	46.5%	23.5%	30.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.323[a]	2	.313
Likelihood Ratio	2.375	2	.305
Linear-by-Linear Association	.582	1	.445
N of Valid Cases	217		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.76.

Table C.33 Cross-tabulation of knowledge links by percentage of researchers/engineers in the firm and increment in capability for mature technology firms.

Percentage of researchers-engineers to total employees * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Percentage of researchers-engineers to total employees	more than 50%	Count	4	6	5	15
		% within Percentage of researchers-engineers to total employees	26.7%	40.0%	33.3%	100.0%
		% within Increment in capability	3.5%	14.0%	15.2%	7.9%
	less than 49%	Count	111	37	28	176
		% within Percentage of researchers-engineers to total employees	63.1%	21.0%	15.9%	100.0%
		% within Increment in capability	96.5%	86.0%	84.8%	92.1%
Total		Count	115	43	33	191
		% within Percentage of researchers-engineers to total employees	60.2%	22.5%	17.3%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.682[a]	2	.021
Likelihood Ratio	7.562	2	.023
Linear-by-Linear Association	6.745	1	.009
N of Valid Cases	191		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 2.59.

Table C.34 Cross-tabulation of knowledge links by manager specifications related to academic experiences and increment in capability for all firms.

Manager specifications related to education & academic experience * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Manager specifications related to education & academic experience	foreign university degree	Count	41	26	25	92
		% within Manager specifications related to education & academic experience	44.6%	28.3%	27.2%	100.0%
		% within Increment in capability	19.0%	27.7%	25.5%	22.5%
	national university degree	Count	156	65	71	292
		% within Manager specifications related to education & academic experience	53.4%	22.3%	24.3%	100.0%
		% within Increment in capability	72.2%	69.1%	72.4%	71.6%
	no degree	Count	19	3	2	24
		% within Manager specifications related to education & academic experience	79.2%	12.5%	8.3%	100.0%
		% within Increment in capability	8.8%	3.2%	2.0%	5.9%
Total		Count	216	94	98	408
		% within Manager specifications related to education & academic experience	52.9%	23.0%	24.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.523[a]	4	.049
Likelihood Ratio	10.157	4	.038
Linear-by-Linear Association	5.934	1	.015
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.53.

Table C.35 Cross-tabulation of knowledge links by manager specifications related to academic experiences and increment in capability for science-based technology firms.

Manager specifications related to education & academic experience * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Manager specifications related to education & academic experience	foreign university degree	Count	27	22	22	71
		% within Manager specifications related to education & academic experience	38.0%	31.0%	31.0%	100.0%
		% within Increment in capability	26.7%	43.1%	33.8%	32.7%
	national university degree	Count	56	26	41	123
		% within Manager specifications related to education & academic experience	45.5%	21.1%	33.3%	100.0%
		% within Increment in capability	55.4%	51.0%	63.1%	56.7%
	no degree	Count	18	3	2	23
		% within Manager specifications related to education & academic experience	78.3%	13.0%	8.7%	100.0%
		% within Increment in capability	17.8%	5.9%	3.1%	10.6%
Total		Count	101	51	65	217
		% within Manager specifications related to education & academic experience	46.5%	23.5%	30.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.124[a]	4	.011
Likelihood Ratio	13.752	4	.008
Linear-by-Linear Association	5.821	1	.016
N of Valid Cases	217		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.41.

Table C.36 Cross-tabulation of knowledge links by manager specifications related to academic experiences and increment in capability for mature technology firms.

Manager specifications related to education & academic experience * Increment in capability Crosstabulation

			Increment in capability			Total
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	
Manager specifications related to education & academic experience	foreign university degree	Count	14	4	3	21
		% within Manager specifications related to education & academic experience	66.7%	19.0%	14.3%	100.0%
		% within Increment in capability	12.2%	9.3%	9.1%	11.0%
	national university degree	Count	100	39	30	169
		% within Manager specifications related to education & academic experience	59.2%	23.1%	17.8%	100.0%
		% within Increment in capability	87.0%	90.7%	90.9%	88.5%
	no degree	Count	1	0	0	1
		% within Manager specifications related to education & academic experience	100.0%	.0%	.0%	100.0%
		% within Increment in capability	.9%	.0%	.0%	.5%
Total		Count	115	43	33	191
		% within Manager specifications related to education & academic experience	60.2%	22.5%	17.3%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.103[a]	4	.894
Likelihood Ratio	1.465	4	.833
Linear-by-Linear Association	.169	1	.681
N of Valid Cases	191		

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is .17.

Table C.37 Cross-tabulation of knowledge links by manager specifications related to industrial experiences and increment in capability for all firms.

Manager specifications related to industrial experiences * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Manager specifications related to industrial experiences	work experience at a firm abroad	Count	22	10	14	46
		% within Manager specifications related to industrial experiences	47.8%	21.7%	30.4%	100.0%
		% within Increment in capability	10.2%	10.6%	14.3%	11.3%
	work experience at a domestic firm	Count	190	84	84	358
		% within Manager specifications related to industrial experiences	53.1%	23.5%	23.5%	100.0%
		% within Increment in capability	88.0%	89.4%	85.7%	87.7%
	no experience	Count	4	0	0	4
		% within Manager specifications related to industrial experiences	100.0%	.0%	.0%	100.0%
		% within Increment in capability	1.9%	.0%	.0%	1.0%
Total		Count	216	94	98	408
		% within Manager specifications related to industrial experiences	52.9%	23.0%	24.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.680[a]	4	.322
Likelihood Ratio	6.159	4	.188
Linear-by-Linear Association	2.113	1	.146
N of Valid Cases	408		

a. 3 cells (33.3%) have expected count less than 5. The minimum expected count is .92.

Table C.38 Cross-tabulation of knowledge links by manager specifications related to industrial experiences and increment in capability for science-based technology firms.

Manager specifications related to industrial experiences * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Manager specifications related to industrial experiences	work experience at a firm abroad	Count	18	10	14	42
		% within Manager specifications related to industrial experiences	42.9%	23.8%	33.3%	100.0%
		% within Increment in capability	17.8%	19.6%	21.5%	19.4%
	work experience at a domestic firm	Count	79	41	51	171
		% within Manager specifications related to industrial experiences	46.2%	24.0%	29.8%	100.0%
		% within Increment in capability	78.2%	80.4%	78.5%	78.8%
	no experience	Count	4	0	0	4
		% within Manager specifications related to industrial experiences	100.0%	.0%	.0%	100.0%
		% within Increment in capability	4.0%	.0%	.0%	1.8%
Total		Count	101	51	65	217
		% within Manager specifications related to industrial experiences	46.5%	23.5%	30.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.900[a]	4	.298
Likelihood Ratio	6.422	4	.170
Linear-by-Linear Association	1.363	1	.243
N of Valid Cases	217		

a. 3 cells (33.3%) have expected count less than 5. The minimum expected count is .94.

Table C.39 Cross-tabulation of knowledge links by manager specifications related to industrial experiences and increment in capability for mature technology firms.

Manager specifications related to industrial experiences * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Manager specifications related to industrial experiences	work experience at a firm abroad	Count	4	0	0	4
		% within Manager specifications related to industrial experiences	100.0%	.0%	.0%	100.0%
		% within Increment in capability	3.5%	.0%	.0%	2.1%
	work experience at a domestic firm	Count	111	43	33	187
		% within Manager specifications related to industrial experiences	59.4%	23.0%	17.6%	100.0%
		% within Increment in capability	96.5%	100.0%	100.0%	97.9%
Total		Count	115	43	33	191
		% within Manager specifications related to industrial experiences	60.2%	22.5%	17.3%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.700[a]	2	.259
Likelihood Ratio	4.115	2	.128
Linear-by-Linear Association	2.241	1	.134
N of Valid Cases	191		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is .69.

Table C.40 Cross-tabulation of knowledge links by R&D activities and increment in capability for all firms.

R&D activities * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
R&D activities	primary	Count	1	3	25	29
		% within R&D activities	3.4%	10.3%	86.2%	100.0%
		% within Increment in capability	.5%	3.2%	25.5%	7.1%
	active	Count	10	13	18	41
		% within R&D activities	24.4%	31.7%	43.9%	100.0%
		% within Increment in capability	4.6%	13.8%	18.4%	10.0%
	none	Count	205	78	55	338
		% within R&D activities	60.7%	23.1%	16.3%	100.0%
		% within Increment in capability	94.9%	83.0%	56.1%	82.8%
Total		Count	216	94	98	408
		% within R&D activities	52.9%	23.0%	24.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	88.777[a]	4	.000
Likelihood Ratio	81.302	4	.000
Linear-by-Linear Association	78.330	1	.000
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.68.

Table C.41 Cross-tabulation of knowledge links by R&D activities and increment in capability for science-based technology firms.

R&D activities * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
R&D activities	primary	Count	1	2	23	26
		% within R&D activities	3.8%	7.7%	88.5%	100.0%
		% within Increment in capability	1.0%	3.9%	35.4%	12.0%
	active	Count	6	8	14	28
		% within R&D activities	21.4%	28.6%	50.0%	100.0%
		% within Increment in capability	5.9%	15.7%	21.5%	12.9%
	none	Count	94	41	28	163
		% within R&D activities	57.7%	25.2%	17.2%	100.0%
		% within Increment in capability	93.1%	80.4%	43.1%	75.1%
Total		Count	101	51	65	217
		% within R&D activities	46.5%	23.5%	30.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	63.925[a]	4	.000
Likelihood Ratio	63.244	4	.000
Linear-by-Linear Association	56.099	1	.000
N of Valid Cases	217		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.11.

Table C.42 Cross-tabulation of knowledge links by R&D activities and increment in capability for mature technology firms.

R&D activities * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
R&D activities	primary	Count	0	1	2	3
		% within R&D activities	.0%	33.3%	66.7%	100.0%
		% within Increment in capability	.0%	2.3%	6.1%	1.6%
	active	Count	4	5	4	13
		% within R&D activities	30.8%	38.5%	30.8%	100.0%
		% within Increment in capability	3.5%	11.6%	12.1%	6.8%
	none	Count	111	37	27	175
		% within R&D activities	63.4%	21.1%	15.4%	100.0%
		% within Increment in capability	96.5%	86.0%	81.8%	91.6%
Total		Count	115	43	33	191
		% within R&D activities	60.2%	22.5%	17.3%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.701[a]	4	.020
Likelihood Ratio	11.592	4	.021
Linear-by-Linear Association	10.773	1	.001
N of Valid Cases	191		

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is .52.

Table C.43 Cross-tabulation of knowledge links by design activities and increment in capability for all firms.

Design activities * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Design activities	non-trivial	Count	14	33	68	115
		% within Design activities	12.2%	28.7%	59.1%	100.0%
		% within Increment in capability	6.5%	35.1%	69.4%	28.2%
	trivial+none	Count	202	61	30	293
		% within Design activities	68.9%	20.8%	10.2%	100.0%
		% within Increment in capability	93.5%	64.9%	30.6%	71.8%
Total		Count	216	94	98	408
		% within Design activities	52.9%	23.0%	24.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	134.683[a]	2	.000
Likelihood Ratio	139.020	2	.000
Linear-by-Linear Association	134.078	1	.000
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 26.50.

Table C.44 Cross-tabulation of knowledge links by design activities and increment in capability for science-based technology firms.

Design activities * Increment in capability Crosstabulation

			Increment in capability			Total
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	
Design activities	non-trivial	Count	9	15	44	68
		% within Design activities	13.2%	22.1%	64.7%	100.0%
		% within Increment in capability	8.9%	29.4%	67.7%	31.3%
	trivial+none	Count	92	36	21	149
		% within Design activities	61.7%	24.2%	14.1%	100.0%
		% within Increment in capability	91.1%	70.6%	32.3%	68.7%
Total		Count	101	51	65	217
		% within Design activities	46.5%	23.5%	30.0%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	63.623[a]	2	.000
Likelihood Ratio	65.568	2	.000
Linear-by-Linear Association	61.920	1	.000
N of Valid Cases	217		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 15.98.

Table C.45 Cross-tabulation of knowledge links by design activities and increment in capability for mature technology firms.

Design activities * Increment in capability Crosstabulation

			Increment in capability			
			operational capability or no capability acquired	improvement of product or process technology	development of product or process technology	Total
Design activities	non-trivial	Count	5	18	24	47
		% within Design activities	10.6%	38.3%	51.1%	100.0%
		% within Increment in capability	4.3%	41.9%	72.7%	24.6%
	trivial+none	Count	110	25	9	144
		% within Design activities	76.4%	17.4%	6.3%	100.0%
		% within Increment in capability	95.7%	58.1%	27.3%	75.4%
Total		Count	115	43	33	191
		% within Design activities	60.2%	22.5%	17.3%	100.0%
		% within Increment in capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	73.530[a]	2	.000
Likelihood Ratio	74.875	2	.000
Linear-by-Linear Association	72.966	1	.000
N of Valid Cases	191		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.12.

APPENDIX D

Table D.1 Cross-tabulation of knowledge links by origin and period for all firms.

origin of link * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
origin of link	foreign	Count	19	83	131	233
		% within origin of link	8.2%	35.6%	56.2%	100.0%
		% within Period	70.4%	58.9%	54.6%	57.1%
	domestic	Count	8	58	109	175
		% within origin of link	4.6%	33.1%	62.3%	100.0%
		% within Period	29.6%	41.1%	45.4%	42.9%
Total		Count	27	141	240	408
		% within origin of link	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.741[a]	2	.254
Likelihood Ratio	2.817	2	.245
Linear-by-Linear Association	2.429	1	.119
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 11.58.

Table D.2 Cross-tabulation of knowledge links by origin and period for science-based and mature technology firms.

origin of link * Period * Type of firm Crosstabulation

Type of firm				Period 1967-1981	Period 1982-1996	Period 1997-2001	Total
mature firms	origin of link	foreign	Count	11	33	67	111
			% within origin of link	9.9%	29.7%	60.4%	100.0%
			% within Period	68.8%	51.6%	60.4%	58.1%
		domestic	Count	5	31	44	80
			% within origin of link	6.3%	38.8%	55.0%	100.0%
			% within Period	31.3%	48.4%	39.6%	41.9%
	Total		Count	16	64	111	191
			% within origin of link	8.4%	33.5%	58.1%	100.0%
			% within Period	100.0%	100.0%	100.0%	100.0%
science-based firms	origin of link	foreign	Count	8	50	64	122
			% within origin of link	6.6%	41.0%	52.5%	100.0%
			% within Period	72.7%	64.9%	49.6%	56.2%
		domestic	Count	3	27	65	95
			% within origin of link	3.2%	28.4%	68.4%	100.0%
			% within Period	27.3%	35.1%	50.4%	43.8%
	Total		Count	11	77	129	217
			% within origin of link	5.1%	35.5%	59.4%	100.0%
			% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

Type of firm		Value	df	Asymp. Sig. (2-sided)
mature firms	Pearson Chi-Square	2.102[a]	2	.350
	Likelihood Ratio	2.115	2	.347
	Linear-by-Linear Association	.032	1	.858
	N of Valid Cases	191		
science-based firms	Pearson Chi-Square	5.882[b]	2	.053
	Likelihood Ratio	5.974	2	.050
	Linear-by-Linear Association	5.703	1	.017
	N of Valid Cases	217		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.70.

b. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 4.82.

Table D.3 Cross-tabulation of knowledge links by source and period for all firms.

type of actor differentiating own engineer * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
type of actor differentiating own engineer	firm	Count	22	89	134	245
		% within type of actor differentiating own engineer	9.0%	36.3%	54.7%	100.0%
		% within Period	81.5%	63.1%	55.8%	60.0%
	institute	Count	0	24	71	95
		% within type of actor differentiating own engineer	.0%	25.3%	74.7%	100.0%
		% within Period	.0%	17.0%	29.6%	23.3%
	intra-firm	Count	5	28	35	68
		% within type of actor differentiating own engineer	7.4%	41.2%	51.5%	100.0%
		% within Period	18.5%	19.9%	14.6%	16.7%
Total		Count	27	141	240	408
		% within type of actor differentiating own engineer	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	17.291[a]	4	.002
Likelihood Ratio	23.279	4	.000
Linear-by-Linear Association	1.197	1	.274
N of Valid Cases	408		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 4.50.

Table D.4 Cross-tabulation of knowledge links by source and period for science-based and mature technology firms.

type of actor differentiating own engineer * Period * Type of firm Crosstabulation

Type of firm				Period 1967-1981	Period 1982-1996	Period 1997-2001	Total
mature firms	type of actor differentiating own engineer	firm	Count	13	39	74	126
			% within type of actor differentiating own engineer	10.3%	31.0%	58.7%	100.0%
			% within Period	81.3%	60.9%	66.7%	66.0%
		institute	Count	0	9	29	38
			% within type of actor differentiating own engineer	.0%	23.7%	76.3%	100.0%
			% within Period	.0%	14.1%	26.1%	19.9%
		intra-firm	Count	3	16	8	27
			% within type of actor differentiating own engineer	11.1%	59.3%	29.6%	100.0%
			% within Period	18.8%	25.0%	7.2%	14.1%
	Total		Count	16	64	111	191
			% within type of actor differentiating own engineer	8.4%	33.5%	58.1%	100.0%
			% within Period	100.0%	100.0%	100.0%	100.0%
science-based firms	type of actor differentiating own engineer	firm	Count	9	50	60	119
			% within type of actor differentiating own engineer	7.6%	42.0%	50.4%	100.0%
			% within Period	81.8%	64.9%	46.5%	54.8%
		institute	Count	0	15	42	57
			% within type of actor differentiating own engineer	.0%	26.3%	73.7%	100.0%
			% within Period	.0%	19.5%	32.6%	26.3%
		intra-firm	Count	2	12	27	41
			% within type of actor differentiating own engineer	4.9%	29.3%	65.9%	100.0%
			% within Period	18.2%	15.6%	20.9%	18.9%
	Total		Count	11	77	129	217
			% within type of actor differentiating own engineer	5.1%	35.5%	59.4%	100.0%
			% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

Type of firm		Value	df	Asymp. Sig. (2-sided)
mature firms	Pearson Chi-Square	16.618[a]	4	.002
	Likelihood Ratio	19.505	4	.001
	Linear-by-Linear Association	1.070	1	.301
	N of Valid Cases	191		
science-based firms	Pearson Chi-Square	11.438[b]	4	.022
	Likelihood Ratio	14.157	4	.007
	Linear-by-Linear Association	5.816	1	.016
	N of Valid Cases	217		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.26.

b. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.08.

Table D.5 Distribution of links by source, origin and period for all firms

Periods	1967-1981		1982-1996		1997-2001	
	Count	% links	Count	% links	Count	% links
TYPE OF SOURCE						
Firm	22	81.5%	89	63.1%	134	55.8%
of which foreign firm	19	70.4%	75	53.2%	115	47.9%
of which domestic firm	3	11.1%	14	9.9%	19	7.9%
Institute	0	0.0%	24	17.0%	70	29.2%
of which foreign institute	0	0.0%	8	5.7%	16	6.7%
of which domestic institute	0	0.0%	16	11.3%	54	22.5%
Intra-firm	5	18.5%	28	19.6%	35	14.6%
All	27	100%	141	100%	240	100%

Table D.6 Distribution of links by source, origin and period for science-based technology firms

Periods	1967-1981		1982-1996		1997-2001	
	Count	% links	Count	% links	Count	% links
TYPE OF SOURCE						
Firm	9	81.8%	50	64.9%	61	47.3%
of which foreign firm	8	72.7%	44	57.1%	54	41.9%
of which domestic firm	1	9.1%	6	7.8%	7	5.4%
Institute	0	0.0%	15	19.5%	41	31.8%
of which foreign institute	0	0.0%	6	7.8%	10	7.8%
of which domestic institute	0	0.0%	9	11.7%	31	24.0%
Intra-firm	2	18.2%	12	15.6%	27	20.9%
All	11	100%	77	100%	129	100%

Table D.7 Distribution of links by source, origin and period for mature technology firms

Periods	1967-1981		1982-1996		1997-2001	
	Count	% links	Count	% links	Count	% links
TYPE OF SOURCE						
Firm	13	81.3%	39	60.9%	74	66.7%
of which foreign firm	11	68.8%	31	48.4%	61	55.0%
of which domestic firm	2	12.5%	8	12.5%	13	11.7%
Institute	0	0.0%	9	14.1%	29	26.1%
of which foreign institute	0	0.0%	2	3.1%	6	5.4%
of which domestic institute	0	0.0%	7	10.9%	23	20.7%
Intra-firm	3	18.8%	16	25.0%	8	7.2%
All	16	100%	64	100%	111	100%

Table D.8 Density of links by period and industry (knowledge links per firm per year)

Period	For all firms[a]	For science-based technology firms[b]	For mature technology firms[c]
1967-1981	0.52	0.73	0.39
1982-1996	0.72	0.84	0.59
1997-2001	2.54	2.62	2.47

a N=408, b N=217, c N=191.
Source: Author's own calculations.

Table D.9 Cross-tabulation of knowledge links by increment in capability and period for all firms.

Increment in capability * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Increment in capability	operational capability or no capability acquired	Count	26	94	96	216
		% within Increment in capability	12.0%	43.5%	44.4%	100.0%
		% within Period	96.3%	66.7%	40.0%	52.9%
	improvement of process or product technology	Count	1	38	55	94
		% within Increment in capability	1.1%	40.4%	58.5%	100.0%
		% within Period	3.7%	27.0%	22.9%	23.0%
	development of product or process technology	Count	0	9	89	98
		% within Increment in capability	.0%	9.2%	90.8%	100.0%
		% within Period	.0%	6.4%	37.1%	24.0%
Total		Count	27	141	240	408
		% within Increment in capability	6.6%	34.6%	58.8%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	69.312[a]	4	.000
Likelihood Ratio	81.754	4	.000
Linear-by-Linear Association	60.641	1	.000
N of Valid Cases	408		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.22.

Table D.10 Cross-tabulation of knowledge links by increment in capability and period for science-based technology firms.

Increment in capability * Period Crosstabulation

			Period			Total
			1967-1981	1982-1996	1997-2001	
Increment in capability	operational capability or no capability acquired	Count	11	47	43	101
		% within Increment in capability	10.9%	46.5%	42.6%	100.0%
		% within Period	100.0%	61.0%	33.3%	46.5%
	improvement of process or product technology	Count	0	21	30	51
		% within Increment in capability	.0%	41.2%	58.8%	100.0%
		% within Period	.0%	27.3%	23.3%	23.5%
	development of product or process technology	Count	0	9	56	65
		% within Increment in capability	.0%	13.8%	86.2%	100.0%
		% within Period	.0%	11.7%	43.4%	30.0%
Total		Count	11	77	129	217
		% within Increment in capability	5.1%	35.5%	59.4%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	37.791[a]	4	.000
Likelihood Ratio	43.835	4	.000
Linear-by-Linear Association	33.798	1	.000
N of Valid Cases	217		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.59.

Table D.11 Cross-tabulation of knowledge links by increment in capability and period for mature technology firms.

Increment in capability * Period Crosstabulation

			Period			
			1967-1981	1982-1996	1997-2001	Total
Increment in capability	operational capability or no capability acquired	Count	15	47	53	115
		% within Increment in capability	13.0%	40.9%	46.1%	100.0%
		% within Period	93.8%	73.4%	47.7%	60.2%
	improvement of process or product technology	Count	1	17	25	43
		% within Increment in capability	2.3%	39.5%	58.1%	100.0%
		% within Period	6.3%	26.6%	22.5%	22.5%
	development of product or process technology	Count	0	0	33	33
		% within Increment in capability	.0%	.0%	100.0%	100.0%
		% within Period	.0%	.0%	29.7%	17.3%
Total		Count	16	64	111	191
		% within Increment in capability	8.4%	33.5%	58.1%	100.0%
		% within Period	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.842[a]	4	.000
Likelihood Ratio	46.275	4	.000
Linear-by-Linear Association	27.049	1	.000
N of Valid Cases	191		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.76.

Table D.12 Cross-tabulation of knowledge links by lagged capability increment and origin of link for all firms.

Stock Capability * Origin of Link Crosstabulation

			Origin of Link		
			foreign	domestic	Total
Stock Capability	operational capability or no capability acquired	Count	132	61	193
		% within Stock Capability	68.4%	31.6%	100.0%
		% within Origin of Link	61.4%	43.0%	54.1%
	improvement of process or product technology	Count	42	42	84
		% within Stock Capability	50.0%	50.0%	100.0%
		% within Origin of Link	19.5%	29.6%	23.5%
	development of product or process technology	Count	41	39	80
		% within Stock Capability	51.3%	48.8%	100.0%
		% within Origin of Link	19.1%	27.5%	22.4%
Total		Count	215	142	357
		% within Stock Capability	60.2%	39.8%	100.0%
		% within Origin of Link	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.733[a]	2	.003
Likelihood Ratio	11.760	2	.003
Linear-by-Linear Association	9.240	1	.002
N of Valid Cases	357		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 31.82.

Table D.13 Cross-tabulation of knowledge links by lagged capability increment and origin of link for science-based technology firms.

Stock Capability * Origin of Link Crosstabulation

			Origin of Link		
			foreign	domestic	Total
Stock Capability	operational capability or no capability acquired	Count	59	31	90
		% within Stock Capability	65.6%	34.4%	100.0%
		% within Origin of Link	53.6%	38.8%	47.4%
	improvement of process or product technology	Count	26	21	47
		% within Stock Capability	55.3%	44.7%	100.0%
		% within Origin of Link	23.6%	26.3%	24.7%
	development of product or process technology	Count	25	28	53
		% within Stock Capability	47.2%	52.8%	100.0%
		% within Origin of Link	22.7%	35.0%	27.9%
Total		Count	110	80	190
		% within Stock Capability	57.9%	42.1%	100.0%
		% within Origin of Link	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.796[a]	2	.091
Likelihood Ratio	4.803	2	.091
Linear-by-Linear Association	4.755	1	.029
N of Valid Cases	190		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 19.79.

Table D.14 Cross-tabulation of knowledge links by lagged capability increment and origin of link for mature technology firms.

Stock Capability * Origin of Link Crosstabulation

			Origin of Link		Total
			foreign	domestic	
Stock Capability	operational capability or no capability acquired	Count	73	30	103
		% within Stock Capability	70.9%	29.1%	100.0%
		% within Origin of Link	69.5%	48.4%	61.7%
	improvement of process or product technology	Count	16	21	37
		% within Stock Capability	43.2%	56.8%	100.0%
		% within Origin of Link	15.2%	33.9%	22.2%
	development of product or process technology	Count	16	11	27
		% within Stock Capability	59.3%	40.7%	100.0%
		% within Origin of Link	15.2%	17.7%	16.2%
Total		Count	105	62	167
		% within Stock Capability	62.9%	37.1%	100.0%
		% within Origin of Link	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.083[a]	2	.011
Likelihood Ratio	8.925	2	.012
Linear-by-Linear Association	3.790	1	.052
N of Valid Cases	167		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 10.02.

Table D.15 Cross-tabulation of knowledge links by lagged capability increment, origin of link and period for all firms established up to 1981.

Origin of Link * Stock Capability * Period Crosstabulation for restricted sample of firms established up to 1981 N=148

Period				Stock Capability: operational capability or no capability acquired	Stock Capability: improvement of process or product technology	Stock Capability: development of product or process technology	Total
1967-1981	Origin of Link	foreign	Count	13			13
			% within Origin of Link	100.0%			100.0%
			% within Stock Capability	92.9%			92.9%
		intra-organizational	Count	1			1
			% within Origin of Link	100.0%			100.0%
			% within Stock Capability	7.1%			7.1%
	Total		Count	14			14
			% within Origin of Link	100.0%			100.0%
			% within Stock Capability	100.0%			100.0%
1982-1996	Origin of Link	foreign	Count	22	4	2	28
			% within Origin of Link	78.6%	14.3%	7.1%	100.0%
			% within Stock Capability	78.6%	36.4%	40.0%	63.6%
		intra-organizational	Count	4	5	2	11
			% within Origin of Link	36.4%	45.5%	18.2%	100.0%
			% within Stock Capability	14.3%	45.5%	40.0%	25.0%
		intra-firm	Count	2	2	1	5
			% within Origin of Link	40.0%	40.0%	20.0%	100.0%
			% within Stock Capability	7.1%	18.2%	20.0%	11.4%
	Total		Count	28	11	5	44
			% within Origin of Link	63.6%	25.0%	11.4%	100.0%
			% within Stock Capability	100.0%	100.0%	100.0%	100.0%
1997-2001	Origin of Link	foreign	Count	30	11	13	54
			% within Origin of Link	55.6%	20.4%	24.1%	100.0%
			% within Stock Capability	69.8%	61.1%	44.8%	60.0%
		intra-organizational	Count	9	4	11	24
			% within Origin of Link	37.5%	16.7%	45.8%	100.0%
			% within Stock Capability	20.9%	22.2%	37.9%	26.7%
		intra-firm	Count	4	3	5	12
			% within Origin of Link	33.3%	25.0%	41.7%	100.0%
			% within Stock Capability	9.3%	16.7%	17.2%	13.3%
	Total		Count	43	18	29	90
			% within Origin of Link	47.8%	20.0%	32.2%	100.0%
			% within Stock Capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

Period		Value	df	Asymp. Sig. (2-sided)
1967-1981	Pearson Chi-Square	.[a]		
	N of Valid Cases	14		
1982-1996	Pearson Chi-Square	7.500[b]	4	.112
	Likelihood Ratio	7.477	4	.113
	Linear-by-Linear Association	4.757	1	.029
	N of Valid Cases	44		
1997-2001	Pearson Chi-Square	4.850[c]	4	.303
	Likelihood Ratio	4.836	4	.305
	Linear-by-Linear Association	3.612	1	.057
	N of Valid Cases	90		

a. No statistics are computed because Stock Capability is a constant.

b. 6 cells (66.7%) have expected count less than 5. The minimum expected count is .57.

c. 3 cells (33.3%) have expected count less than 5. The minimum expected count is 2.40.

Table D.16 Cross-tabulation of knowledge links by lagged capability increment, origin of link and period for all firms established 1982 onwards

Origin of Link * Stock Capability * Period Crosstabulation for restricted sample of firms establsihed 1982 onwards N=209

Period				Stock Capability: operational capability or no capability acquired	Stock Capability: improvement of process or product technology	Stock Capability: development of product or process technology	Total
1982-1996	Origin of Link	foreign	Count	34	8	2	44
			% within Origin of Link	77.3%	18.2%	4.5%	100.0%
			% within Stock Capability	73.9%	61.5%	66.7%	71.0%
		intra-organizational	Count	10	3	0	13
			% within Origin of Link	76.9%	23.1%	.0%	100.0%
			% within Stock Capability	21.7%	23.1%	.0%	21.0%
		intra-firm	Count	2	2	1	5
			% within Origin of Link	40.0%	40.0%	20.0%	100.0%
			% within Stock Capability	4.3%	15.4%	33.3%	8.1%
	Total		Count	46	13	3	62
			% within Origin of Link	74.2%	21.0%	4.8%	100.0%
			% within Stock Capability	100.0%	100.0%	100.0%	100.0%
1997-2001	Origin of Link	foreign	Count	33	19	24	76
			% within Origin of Link	43.4%	25.0%	31.6%	100.0%
			% within Stock Capability	53.2%	45.2%	55.8%	51.7%
		intra-organizational	Count	17	18	14	49
			% within Origin of Link	34.7%	36.7%	28.6%	100.0%
			% within Stock Capability	27.4%	42.9%	32.6%	33.3%
		intra-firm	Count	12	5	5	22
			% within Origin of Link	54.5%	22.7%	22.7%	100.0%
			% within Stock Capability	19.4%	11.9%	11.6%	15.0%
	Total		Count	62	42	43	147
			% within Origin of Link	42.2%	28.6%	29.3%	100.0%
			% within Stock Capability	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

Period		Value	df	Asymp. Sig. (2-sided)
1982-1996	Pearson Chi-Square	4.924[a]	4	.295
	Likelihood Ratio	4.482	4	.345
	Linear-by-Linear Association	2.030	1	.154
	N of Valid Cases	62		
1997-2001	Pearson Chi-Square	3.690[b]	4	.450
	Likelihood Ratio	3.627	4	.459
	Linear-by-Linear Association	.452	1	.502
	N of Valid Cases	147		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is .24.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.29.

Table D.17 Cross-tabulation of knowledge links by lagged capability increment and type of source for all firms.

Stock Capability * Type of actor Crosstabulation

			Type of actor			Total
			firm	institute	intra-firm	
Stock Capability	operational capability or no capability acquired	Count	140	33	20	193
		% within Stock Capability	72.5%	17.1%	10.4%	100.0%
		% within Type of actor	62.8%	36.7%	45.5%	54.1%
	improvement of process or product technology	Count	43	29	12	84
		% within Stock Capability	51.2%	34.5%	14.3%	100.0%
		% within Type of actor	19.3%	32.2%	27.3%	23.5%
	development of product or process technology	Count	40	28	12	80
		% within Stock Capability	50.0%	35.0%	15.0%	100.0%
		% within Type of actor	17.9%	31.1%	27.3%	22.4%
Total		Count	223	90	44	357
		% within Stock Capability	62.5%	25.2%	12.3%	100.0%
		% within Type of actor	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.133[a]	4	.001
Likelihood Ratio	19.245	4	.001
Linear-by-Linear Association	10.575	1	.001
N of Valid Cases	357		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 9.86.

Table D.18 Cross-tabulation of knowledge links by lagged capability increment and type of source for science-based technology firms.

Stock Capability * Type of actor Crosstabulation

			Type of actor			Total
			firm	institute	intra-firm	
Stock Capability	operational capability or no capability acquired	Count	60	19	11	90
		% within Stock Capability	66.7%	21.1%	12.2%	100.0%
		% within Type of actor	55.6%	36.5%	36.7%	47.4%
	improvement of process or product technology	Count	23	16	8	47
		% within Stock Capability	48.9%	34.0%	17.0%	100.0%
		% within Type of actor	21.3%	30.8%	26.7%	24.7%
	development of product or process technology	Count	25	17	11	53
		% within Stock Capability	47.2%	32.1%	20.8%	100.0%
		% within Type of actor	23.1%	32.7%	36.7%	27.9%
Total		Count	108	52	30	190
		% within Stock Capability	56.8%	27.4%	15.8%	100.0%
		% within Type of actor	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.997[a]	4	.136
Likelihood Ratio	7.014	4	.135
Linear-by-Linear Association	5.154	1	.023
N of Valid Cases	190		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.42.

Table D.19 Cross-tabulation of knowledge links by lagged capability increment and type of source for mature technology firms.

Stock Capability * Type of actor Crosstabulation

			Type of actor			Total
			firm	institute	intra-firm	
Stock Capability	operational capability or no capability acquired	Count	80	14	9	103
		% within Stock Capability	77.7%	13.6%	8.7%	100.0%
		% within Type of actor	69.6%	36.8%	64.3%	61.7%
	improvement of process or product technology	Count	20	13	4	37
		% within Stock Capability	54.1%	35.1%	10.8%	100.0%
		% within Type of actor	17.4%	34.2%	28.6%	22.2%
	development of product or process technology	Count	15	11	1	27
		% within Stock Capability	55.6%	40.7%	3.7%	100.0%
		% within Type of actor	13.0%	28.9%	7.1%	16.2%
Total		Count	115	38	14	167
		% within Stock Capability	68.9%	22.8%	8.4%	100.0%
		% within Type of actor	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.145[a]	4	.007
Likelihood Ratio	13.960	4	.007
Linear-by-Linear Association	3.120	1	.077
N of Valid Cases	167		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 2.26.

Table D.20 Cross-tabulation of knowledge links by lagged capability increment and type of source of by origin for all firms.

Stock Capability * Type of actor Crosstabulation

			Type of actor					
			foreign firm	foreign institute	domestic firm	domestic institute	intra-firm	Total
Stock Capability	operational capability or no capability acquired	Count	121	11	19	22	20	193
		% within Stock Capability	62.7%	5.7%	9.8%	11.4%	10.4%	100.0%
		% within Type of actor	63.0%	47.8%	61.3%	32.8%	45.5%	54.1%
	improvement of process or product technology	Count	36	6	7	23	12	84
		% within Stock Capability	42.9%	7.1%	8.3%	27.4%	14.3%	100.0%
		% within Type of actor	18.8%	26.1%	22.6%	34.3%	27.3%	23.5%
	development of product or process technology	Count	35	6	5	22	12	80
		% within Stock Capability	43.8%	7.5%	6.3%	27.5%	15.0%	100.0%
		% within Type of actor	18.2%	26.1%	16.1%	32.8%	27.3%	22.4%
Total		Count	192	23	31	67	44	357
		% within Stock Capability	53.8%	6.4%	8.7%	18.8%	12.3%	100.0%
		% within Type of actor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.921[a]	8	.007
Likelihood Ratio	21.148	8	.007
Linear-by-Linear Association	11.567	1	.001
N of Valid Cases	357		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.15.

Table D.21 Cross-tabulation of knowledge links by lagged capability increment and type of source by origin for science-based technology firms.

Stock Capability * Type of actor Crosstabulation

			Type of actor					
			foreign firm	foreign institute	domestic firm	domestic institute	intra-firm	Total
Stock Capability	operational capability or no capability acquired	Count	52	7	8	12	11	90
		% within Stock Capability	57.8%	7.8%	8.9%	13.3%	12.2%	100.0%
		% within Type of actor	54.7%	46.7%	61.5%	32.4%	36.7%	47.4%
	improvement of process or product technology	Count	21	5	2	11	8	47
		% within Stock Capability	44.7%	10.6%	4.3%	23.4%	17.0%	100.0%
		% within Type of actor	22.1%	33.3%	15.4%	29.7%	26.7%	24.7%
	development of product or process technology	Count	22	3	3	14	11	53
		% within Stock Capability	41.5%	5.7%	5.7%	26.4%	20.8%	100.0%
		% within Type of actor	23.2%	20.0%	23.1%	37.8%	36.7%	27.9%
Total		Count	95	15	13	37	30	190
		% within Stock Capability	50.0%	7.9%	6.8%	19.5%	15.8%	100.0%
		% within Type of actor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.048[a]	8	.338
Likelihood Ratio	9.125	8	.332
Linear-by-Linear Association	5.737	1	.017
N of Valid Cases	190		

a. 4 cells (26.7%) have expected count less than 5. The minimum expected count is 3.22.

Table D.22 Cross-tabulation of knowledge links by lagged capability increment and type of source by origin for mature technology firms.

Stock Capability * Type of actor Crosstabulation

			Type of actor					
			foreign firm	foreign institute	domestic firm	domestic institute	intra-firm	Total
Stock Capability	operational capability or no capability acquired	Count	69	4	11	10	9	103
		% within Stock Capability	67.0%	3.9%	10.7%	9.7%	8.7%	100.0%
		% within Type of actor	71.1%	50.0%	61.1%	33.3%	64.3%	61.7%
	improvement of process or product technology	Count	15	1	5	12	4	37
		% within Stock Capability	40.5%	2.7%	13.5%	32.4%	10.8%	100.0%
		% within Type of actor	15.5%	12.5%	27.8%	40.0%	28.6%	22.2%
	development of product or process technology	Count	13	3	2	8	1	27
		% within Stock Capability	48.1%	11.1%	7.4%	29.6%	3.7%	100.0%
		% within Type of actor	13.4%	37.5%	11.1%	26.7%	7.1%	16.2%
Total		Count	97	8	18	30	14	167
		% within Stock Capability	58.1%	4.8%	10.8%	18.0%	8.4%	100.0%
		% within Type of actor	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.379[a]	8	.019
Likelihood Ratio	17.829	8	.023
Linear-by-Linear Association	4.222	1	.040
N of Valid Cases	167		

a. 8 cells (53.3%) have expected count less than 5. The minimum expected count is 1.29.