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STUDIES IN TECHNOLOGY TRANSFER

Selected cases from Argentina, China, South Africa and Taiwan Province of China




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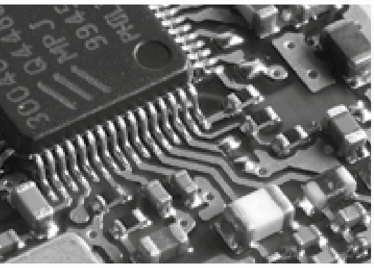

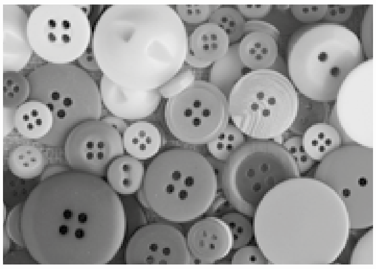

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Preface

This paper builds on ongoing efforts by UNCTAD to investigate the role of the transfer of technology in economic development. It was prepared under UNCTADs mandate to undertake research and analysis in the area of science, technology and innovation (STI) with a focus on making STI capacity an instrument for supporting national development and helping local industry become more competitive, as outlined in the Doha mandate paragraph 56 (p). The paper presents diverse cases which provide contrasting experiences of the role of technology transfer and absorption in the development of four different industries in economies from Africa (South Africa), Asia (Taiwan Province of China and China) and Latin America (Argentina). The issue of technology transfer is of key importance for firms and countries that operate within the technology frontier to build technological and innovation capabilities. These capabilities are critical to enable the upgrading of firms into more complex, skill and knowledge intensive activities, which typically add more value to local production, allow increased productivity and ultimately lead to higher wages, expanding domestic demand and growing economies. The process of upgrading in production is an essential link in the process of building productive capacity and generating structural change as part of the process of economic development.

These studies illustrate the varying approaches that firms and industries in different countries have taken in using international and domestic transfer of technology and combining these transfers with knowledge accumulated through internal effort in order to build stronger capabilities and improve their innovation performance. They also illustrate the substantial variation in policy frameworks, institutional development, levels of policy intervention and underlying strategies implemented by developing-country national and local governments in their quest to promote catch-up with more advanced countries by closing the gaps in scientific, engineering, technological and innovation capabilities and performance.

The paper examines the role of technology transfer in the development of integrated circuits production in Taiwan Province of China, button manufacturing in Qiaotou, China, automobile manufacturing in South Africa and biotechnology development in Argentina. The cases therefore cover high-technology activities (integrated circuits and biotechnology), medium-technology activities (automobiles) and low-technology activities (buttons). It is hoped that this approach illustrates the potential for technology transfer to play a role in activities of widely differing knowledge, technology and skill intensities. These cases represent varying degrees of success in the leveraging of technology transfer and local capability development for industrial development in developing economies. The cases of integrated circuits in Taiwan Province of China and buttons in Qiaotou, China are both highly successful experiences of technological and industrial upgrading that laid the basis for globally competitive industries. In the cases of biotechnology in Argentina and automobiles in South Africa, the results have been more mixed, with slower technological upgrading and a more nuanced picture in terms of the success of industrial upgrading and international competitiveness.

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This paper was prepared by the Policy Reviews Section of the Science, Technology and ICT Branch of the Division on Technology and Logistics, UNCTAD. The preparation of the paper was overseen by Michael Lim under the direction of Angel Gonzalez-Sanz, with the assistance of Marta Perez Cuso on the case of biotechnology in Argentina. Overall guidance was provided by Mongi Hamdi, head of the Branch, and Anne Miroux, Director of the Division. The case studies were written by Rajah Rasiah (integrated circuits in Taiwan Province of China and buttons in China), Anthony Black (automobile industry in South Africa) and Jorge Niosi (biotechnology in Argentina). The analytical framework is based heavily on an input from Rajah Rasiah.

During the preparation of this report, comments were received from Torbjörn Fredrikson and colleagues from the Intellectual Property Unit of the Division on Investment and Enterprise of UNCTAD.

Desktop publishing was carried out by Nathalie Loriot. The cover was designed by Sophie Combette.

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Abbreviations and Acronyms

A$	Argentine peso
AIEC	Automotive Industry Export Council (South Africa)
AIS	Automotive Investment Scheme
ANLIS	National Administration for Health Laboratories and Institutes (Argentina)
ANR	non-reimbursable support (aporte no reembolsable)
APDP	Automotive Production and Development Programme
BERD	business expenditure on R&D
CBU	completely built up
CeSTII	Centre for Scientific, Technological and Innovation Indicators (South Africa)
CKD	completely knocked down
CNC	computer numerically controlled
CNEA	National Atomic Energy Commission (Argentina)
CONABIA	National Commission for Agricultural Biotechnology (Argentina)
CONICET	National Council for Scientific Research (Argentina)
DBF	dedicated biotechnology firm
DNA	deoxyribonucleic acid
DNMA	National Direction of Agricultural Markets (Argentina)
DOST	Department of Science and Technology (South Africa)
DRAM	dynamic random access memory
EPO	erythropoietin
ERSO	Electronic Research Services Organization (Taiwan Province of China)
FDI	foreign direct investment
FONCYT	Scientific and Technology Research Fund (Argentina)
FONTAR	Argentine Technology Fund
GERD	gross expenditure on R&D
GM	genetically modified
GMO	genetically modified organism
GVC	global value chain
HA	hectare
HCV	heavy commercial vehicle
HR	human resources

HSIP	Hsinchu Science-Based Industrial Park
ICT	information and communications technology
IDRC	International Development Research Centre (Canada)
INTA	National Institute for Agricultural Technology (Argentina)
INTI	National Institute for Industrial Technology (Argentina)
IPR	intellectual property rights
IS	innovation system
ISO	International Organization for Standardization
ITRI	Industrial Technology Research Institute (Taiwan Province of China)
JIT	just-in-time (delivery)
LDC	least developed country
LV	light vehicle
merSETA	manufacturing, engineering and related services SETA
MIDP	Motor Industry Development Plan
MRP	materials requirement planning
MRP1	materials resource planning
MRP11	integrated materials resource planning
NAAMSA	National Association of Automobile Manufacturers of South Africa
NIS	national innovation system
NT$	new Taiwan dollar (currency of Taiwan Province of China)
OECD	Organization for Economic Cooperation and Development
OEM	original equipment manufacture
OLI	ownership, location, internalization (framework for FDI)
QCC	quality control circle
R&D	research and development
Rand (R)	currency of South Africa
RCA	Radio Company of America
RFID	radio-frequency identification
RIS	regional innovation system
S&T	science and technology
SAABC	South African Automotive Benchmarking Club
SABS	South African Bureau of Standards
SARS	South African Revenue Service

SENASA	National Service for Health and Agricultural Quality (Argentina)
SETA	Sector Education and Training Authorities
SIS	silicon integrated systems
SME	small and medium-sized enterprise
SPC	statistical process control
SQC	statistical quality control
STI	science, technology and innovation
TAC	Technical Advisory Committee
TCQ	total quality control
TNC	transnational corporation
TPM	total preventive maintenance
TQM	total quality management
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
TSMC	Taiwan Semiconductor Manufacturing Corporation
UMC	United Microelectronics Corporation
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
UNL	National University of Litoral (Argentina)
USDA	United States Department of Agriculture
USPTO	United States Patent and Trademark Office
VLSI	very large-scale integration
WTO	World Trade Organization

Introduction

Economic development has typically involved increasing flows of not only capital and products among countries, but also of knowledge and technology. As part of the development process, knowledge flows from technologically advanced countries and firms with superior national, regional or sector-based innovation systems to less technologically advanced countries and firms with weaker national, regional or sector-based innovation systems. In many cases, government policymakers have intervened to spearhead national or local initiatives aimed at promoting knowledge and technology transfers.[1] Simultaneously, they have implemented policies to increase domestic investment in building national STI capacity, including at the firm level, in universities, research institutes and government bodies. Through foreign knowledge flows and domestic investment in STI, policymakers have sought to build STI capacity in order to promote technological and skill upgrading and build more innovative and internationally competitive domestic industries. The process of narrowing of the technological gap with more technologically advanced countries or firms is sometimes referred to as catching up.[2] This paper contributes to the literature on the role of technology transfer in catching-up experiences in developing countries.

The literature on technology transfer is diverse, with considerable differences in the channels through which technology can flow. Foreign knowledge and technology has in some cases been transferred to firms in host countries through foreign direct investment (FDI) and non-equity modes of operation of transnational corporations (TNCs), or through international trade, the licensing of technology, the movement of people with knowledge and skills (human capital) or imitation (through, for example, reverse engineering). There may be a mix of channels involved, with different intensities of technology flows among these channels. Both can also change over time. The nature and form of these transfers are therefore often complex and arise as a set of processes involving a myriad of sources. Successful technology transfer often requires significant investment in learning by local firms and is far from being an easy, smooth or automatic process. In all successful cases, knowledge and technology from abroad have been accompanied by the development of local firm and industry-level capabilities through investment in training and skills development, R&D and less formal, non R&D-based, learning by doing. The development of strong capabilities builds the absorptive capacity needed to master technologies originating from foreign or local sources.

Technology transfer experiences have also been conditioned by the configuration of the national, regional and sectoral innovation systems in place in host countries. However, the policy direction governments take in facilitating knowledge transfers often varies by industry and country, and depend upon the timing of design and implementation of these strategies. Some tools

1 Technology transfer refers to the transfer of the components of technology from one economic agent to another. These components can include, for example, plant, machinery and equipment, production processes, software, manuals and patents – all of which contain technological knowledge (either codified or uncodified) that is either "embodied" (for example, within machinery or people) or "disembodied". The United Nations Draft Code of Conduct on the Transfer of Technology defines technology transfer as "the transfer of systematic knowledge for the manufacture of a product, for the application of a process or for the rendering of a service and does not extend to the transactions involving the mere sale or mere lease of goods" (UNCTAD, 1985). WIPO (2011) defines technology transfer as "a series of processes for sharing ideas, knowledge, technology and skills with another individual or institution (e.g. a company, a university or a governmental body) and of acquisition by the other of such ideas, knowledge, technologies and skills". Technology transfer can be conceptualized as a process that includes various stages, and requires investment of time and effort by the transferee to access, learn, understand, adapt and use the technology. Technology transfer can take place through different channels, including market (or commercial) and non-market (non-commercial) ones. It may also be contractually based or not. The concept is therefore by its nature very broad, which can easily lead to confusion in discussing the issue of technology transfer.

2 The term "catching up" can be used to denote several different aspects of economic catching up, including narrowing of the gaps between countries (or convergence) in terms of technological capabilities, productivity, economic growth or income level. Technological catching up plays a critical part in all these aspects of catching up with the most advanced economies.

that were used in earlier periods may no longer be available, being proscribed by international economic agreements relating to trade, investment and integration (bilateral or otherwise). The types of policies and strategies vary greatly in terms of the mix, the extent of interventions and the nature of the STI policy measures as well as broader development strategies. Some successful experiences have benefited considerably from FDI. In some others, domestic firms managed to break into global value chains and upgrade through domestic support from embedding institutions and meso organizations.[3] Other, hybrid approaches also exist.

This report uses mainly an inductive evolutionary framework that draws upon interviews and secondary information on the flows of knowledge from abroad that drive technological catch-up.[4] The report examines four different industry cases of technology transfer experiences in four economies. They include integrated circuits production in Taiwan Province of China, button manufacturing in Qiaotou, China, automobiles in South Africa and biotechnology in Argentina. The cases therefore cover high-technology activities (integrated circuits and biotechnology), medium-technology activities (automobiles) and low-technology activities (buttons).[5] They provide a contrast in terms of the degrees of success achieved in the leveraging of technology transfer and local capability development for industrial development. They illustrate the diversity in approaches that have been taken to the development of technological capabilities and the varying role of international technology transfer, in different country and industry contexts, and over different periods of time. What emerges clearly is that paths towards technological development have varied tremendously among different cases, which may be related, inter alia, to different STI policy frameworks and strategies, and differences in broader development strategies (including notably the use of industrial policy to support technological upgrading), that have been pursued in these cases. There may also be variation that results in part from intrinsic differences among the four industries.[6]

3 North (1993) defined institutions as the "rules of the game", while referring to entrepreneurs and organizations as the players. Embedding institutions refer to the regulatory framework facing firms. Meso organizations are intermediary organizations that are established to solve collective action problems faced by firms and individuals.

4 Inductive approaches use an open framework of research where evidence becomes the basis of theorizing.

5 Neither integrated circuits nor buttons were specifically listed in the OECD (2011) technology classifications, which are drawn on the basis of R&D intensities in manufacturing industries. However, integrated circuits and buttons are components of the high-technology industry of computers, and the low-technology industry of textile products, respectively. Biotechnology also does not appear, as it does not represent a manufacturing industry, but rather a set of technologies used in many different industries. It is a high-skill activity and may be associated with the pharmaceuticals industry, which is counted as a high-technology industry. Biotechnology is certainly heavily R&D based. Motor vehicles are included in the medium-technology category (medium-high technology to be specific).

6 Differences among industries or sectors in terms of the technologies and types of knowledge and skills needed for success, the learning process of firms and innovation patterns, are known to exist (see Pavitt, 1984, Malerba, 1992).

Chapter 1. Technology transfer and technological capabilities: Analytical framework

This section discusses the critical issues that are pertinent in the evaluation of technology transfer cases targeted at producing a policy synthesis. Successful firms located in developing countries have often enjoyed technology transfer from TNCs abroad or from national, regional, local or sector-based meso organizations. For example, Samsung's early catch-up in integrated circuits and Hyundai's early development in automobile manufacturing benefited considerably from licensing from TNCs located abroad, as well as capabilities acquired from meso organizations and internal developments (Kim, 1997, 2003). Successful technological catch-up experiences have also been considerably influenced by institutional change and firm-level strategies (Teece, 2009). While recognizing the importance of management capabilities, such as production, accounting, engineering and marketing, as articulated by Teece (2009), these capabilities are difficult to measure and are also often dispersed in a wide range of activities. Hence, the assessment is concentrated on the transfer of technology targeted at raising technological capabilities. The three key concepts important to this investigation are technological capabilities, TNCs and institutional support. The synergizing capacity of technology transfer is typically higher in integrated clusters (Best, 2001).

Foreign sources of knowledge

Firms located in locations (regions or countries) with superior knowledge bases that are endowed with well-developed networks of institutions, meso organizations and firms often enjoy superior technology over firms located in inferior locations. Firms in inferior sites that are seeking to pursue technological upgrading often seek technology transfer from locations with superior knowledge bases. This may be done through acquisitions of technologically strategic firms, licensing agreements that allow the use of particular technologies or flows of knowledge, through movements of human capital carrying experiential knowledge working in the superior knowledge bases (either in firms, universities or in R&D laboratories), and by knowledge circulation between employees in inferior and superior sites. Such sites can be a constellation of microagents (firms and others) and meso organizations (a cluster) located in a particular national, regional, sectoral or local innovation system. Institutions are sometimes established to operate in a particular subnational location rather than throughout the whole country. This may be either because governments prefer focused governance to monitor and appraise upgrading and catch-up, or because their operation is either undesirable or uneconomic if applied to the whole country. National innovation systems are easier to coordinate in small than in large countries. This section discusses technological knowledge transfers through TNCs, licensing, acquisitions, trade and the movement of human capital.

Transnational corporations

There is wide recognition that TNCs have been important sources of cross-border knowledge flows to local firms in developing countries, either from their non-equity operations abroad or through FDI, including complete ownership or joint ventures. However, theoretical arguments over the degree to which they lead to direct and indirect technology transfer to firms in host countries, and how common these transfers are, have remained inconclusive. This is especially the case for FDI in LDCs, where technology spillovers to local firms appear to be particularly weak, in part due to low absorptive capacity (UNCTAD, 2007a). The discourse on the significance of FDI for host developing countries has moved from being an ideological issue to a more empirical one. Critics have in the past argued that asymmetric relations between large global firms and weak developing country governments and firms can produce various harmful effects from what has been termed "defensive conduct" (Lall and Streeten, 1977),[7] which may include, for example, oligopolistic control of markets (Hymer, 1960) or the acquisition and crowding out of efficient local firms. They can likewise bring benefits. In

[7] Industrial organization theorists refer to defensive conduct as self-motivated unproductive behavior that reduces overall economic synergies accruing to the economic agents involved (Greer, 1992).

addition to providing investment and possibly creating employment, FDI has the potential to expose local firms to good or best practices, to competitive discipline, as well as scale economies (Hirschman, 1958; Dunning, 1958), in addition to technology transfer. The implementation of various types of performance requirements[8] placed on foreign investors (relating to, inter alia, technology transfer, R&D, local content, employment, exports and domestic ownership) has been used by many developing countries in an attempt to appropriate these benefits – with mixed results in terms of their effectiveness (UNCTAD, 2003).

One important element in explaining technology transfers is the type of activities that TNCs undertake in host countries. Vernon's (1966) product cycle model argued that only mature production would be relocated to developing locations. However, Helleiner (1973) provided evidence of TNCs fragmenting production and relocating the assembly and processing of the labour-intensive parts of the production of recent products, which countered this argument. The fragmentation of production and outsourcing abroad (or offshoring) of production and other parts of the value chain, including even R&D and design, has progressed rapidly since 1990 with the spread of global and regional value chains. The offshoring of R&D to foreign countries in particular may be more likely to contribute to technology transfer and the building of technological and innovative capability in host countries. This might be contrasted with FDI through the acquisition of local firms that are already undertaking R&D. In this case, TNCs may in practice concentrate their R&D in a limited number of locations within their global networks, potentially affecting how much and what type of R&D is performed in a particular location. Such rationalization may lead to reduced R&D in a specific host country and closure or relocation of some R&D activities elsewhere in the network (often the global or regional headquarters). It might, on the other hand, also lead to limited change or more R&D in that country if it is a preferred location for R&D within the network. The issue of the effects of spread of TNC operations abroad on the size and nature of R&D activities at TNC host country affiliates is not straightforward (UNCTAD, 2005).

Rasiah (1988, 1996), Cantwell (1995), UNCTAD (2005) and Ernst (2006) provide evidence of foreign TNCs offshoring R&D activities into developing countries. It should, nevertheless, be noted that there are relatively few examples of TNCs from developed countries broadening the geographic scope of R&D activities for frontier-level innovation aimed at global markets to countries with weaker innovation systems. In integrated circuits production, Intel's location of a sophisticated R&D plant in Israel is a rare exception that can be explained by the presence there of a pool of competent engineers and scientists.[9] The rarity of the transfer of the most sophisticated R&D plants to developing countries brings into perspective the work of Amsden, Tschang and Goto (2001), who argue that foreign firms retain their most sophisticated activities in their home countries. Nevertheless, UNCTAD (2005) charts the broadening of the geographic scope of R&D by TNCs from developed countries to include developing country locations. The type of linkages that develop with local firms may also help determine whether technology transfers to the latter actually materialize.

Knowledge spillovers from TNCs to local firms *can* happen, and show that latecomer firms can benefit from the presence of foreign TNCs. Under what conditions this happens is not yet adequately understood. The impacts of FDI and non-equity operations of TNCs on knowledge and technology flows to firms in host countries remain sensitive to the details of each case and are therefore nuanced. What is clear is that foreign firms ought to show higher levels of technological capabilities for such spillovers to become useful for local firms. The capacity of the local firm to absorb knowledge spillovers – based largely upon its internal technological capabilities (discussed below) – is an important prerequisite for these spillovers to occur. Using evidence from the Republic of Korea, Kim (1997) argued that the appropriation of potential spillovers from FDI is maximized when local firms build capacity and are able to upgrade from "duplicative" to "creative"

[8] Performance requirements are stipulations, imposed on investors, requiring them to meet specified goals with respect to their operations within a country, typically with the intention to promote investor activities that will help to meet certain development objectives, such as the transfer of technology.

[9] Interview with the managing director and vice-president of Intel Corporation on 29 December 2009 in Penang, Malaysia.

imitation capabilities.[10] Indeed, the first steps for initiating and deepening TNC-based learning and innovation will be to identify the firms with the relevant technologies, appropriable benefits and the requisite institutions required to promote absorption of spillovers (that is, practice targeted FDI promotion).

Hirschman (1958, 1970) strongly argued the need for export orientation to benefit from the discipline and scale economies effects of foreign firms from larger foreign markets in order to promote competition and the development of backward linkages in the host country. Critical in Hirschman's (1977) accounts on FDI is the emphasis on backward linkages, the argument being that rising exports will expand the scale of production and competitiveness and produce opportunities for the formation of backward linkages in the host country. Hirschman argued that the initial entry of FDI in developing countries often created serious demand–supply imbalances owing to the lack of capable domestic suppliers. Hence, policies are essential to develop domestic supply capabilities in local firms and build backward linkages with TNCs.

Although the capacity to absorb new knowledge is easier when the technological gap between the leader and learner is small, Hirschman (1958, 1970) argued that the bigger the gap, the larger the potential for catch-up. Gerschenkron (1962) went further to argue that latecomer countries and firms can acquire knowledge faster, and hence can shorten the catch-up period, because they have examples from developed countries to look at and emulate. Abramowitz (1986) further developed and popularized the catching up concept. These ideas were taken up by more recent economists, such as Reinert (2007, 2009), who argue that emulation (in terms of industrial structure) can be a powerful tool for aiding the design of catch-up strategies in poor countries. Related research on emulation, production structure and development strategies includes Hausmann and Rodrik (2003), Haussman, Hwang and Rodrik (2007), Hidalgo et al (2007), Lin and Chang (2009) and Lin (2012a, b).

International business scholars offered another dimension to the understanding of circumstances when FDI will provide tangible technological benefits to developing countries. Dunning's (1988) eclectic approach (the ownership, location and internalization, or OLI, framework) to explaining FDI and the internationalization of production also addresses the potential for spillovers to host countries. Business scholars added motives for foreign investment to explain the conduct of TNCs in host countries (Dunning, 1988; Narula, 1996; Cantwell and Mudambi, 2005). An important implication is that host country governments looking to attract TNCs, and firms seeking to form alliances with them, need to understand TNCs' motives for undertaking FDI in order to implement strategies to stimulate local spillovers. Developing country firms also use outward FDI as a means of acquiring technologies and knowledge from firms abroad that possess the technologies and knowledge that they seek (for example, the case of RCA in Taiwan Province of China).

The licensing of technology and the acquisition of firms are important tools that developing country firms used to move closer to the technology frontier. There have been many instances of acquisitions of foreign firms, and licensing contracts established with TNCs from developed countries that had no production sites in the acquiring firm's home country (UNCTAD, 2004). In the Republic of Korea, through a series of instances of hiring of foreign human capital (embodied with tacit knowledge gained from working in foreign firms), combined with the acquisition of ailing foreign firms and strategic alliances, Samsung was able to begin the manufacture of 64K DRAM chips in 1982. By 1984 they had reached the frontier of DRAM technology and were manufacturing 256K DRAM chips (Edquist and Jacobsson, 1987; Kim, 1997). LG Electronics, Hyundai and Hynix followed similar patterns of acquiring product technology. Lenovo of China bought the entire IBM computer division to acquire computer manufacturing capabilities. These strategies may be referred to as leveraging strategies.

Central to the literature on leveraging FDI is a national or regional strategy on technological catch-up that focuses on domestic capability-building (Mathews

[10] Whereas duplication refers to identical imitation (replication or copying), creative imitation refers to adaptations or further developments in the technological configuration of particular processes and products, and represents a more advanced level of innovative capability. See also Kim (2003) for more on the process of moving from duplicative to creative imitation capabilities.

and Cho, 2000). While domestic economic agents aim to achieve technology transfer and promote technological catch-up, they are required to combine access to foreign knowledge with the development of local knowledge. Because knowledge has cumulative and path-dependent features, accessing it from mature sources initially will be more economical and faster than the local firm developing it. What is critical from foreign sources is access to knowledge that can be drawn through FDI, imitation, licensing, the acquisition of foreign firms and the hiring of human capital carrying tacit knowledge (that is, skilled labour). Latecomer countries such as Japan and the Republic of Korea, relied extensively on the last two modes to absorb foreign knowledge to accelerate technological catch-up by local firms (Johnson, 1982; Edquist and Jacobssen, 1987; Amsden, 1989; Amsden and Chu, 2003; Wade, 1990; Chang, 1994; Rasiah and Lin, 2005). Singapore and Ireland have continued to rely extensively on FDI to achieve this goal (Best, 2001).

Trade

Trade is another important channel through which technology is transferred from one country to another. Imports of capital goods, in particular machinery and equipment that have embodied knowledge and knowledge from manuals and technology-related services, have been critical in technology flows. Fukasaku (1992) provides evidence how the Japanese absorbed knowledge from imports of machinery and equipment, originally from the United Kingdom of Great Britain and Northern Ireland, and subsequently from Germany, that helped Japanese firms such as Mitsubishi Nagasaki Shipyard to develop their capabilities to eventually build super tankers.

Similarly, Fransman (1986), Freeman (1988) and Amsden (1989) presented evidence of knowledge flows taking place through imports of machinery and equipment, and components, where Japan and the Republic of Korea sequentially stimulated domestic capability building through switching from import-substitution to export-orientation development strategies. Interestingly, Japan and became leading heavy machinery exporters as national firms absorbed imported technology through learning that created the capacity for innovation. Imports of machinery contain embodied knowledge and technology, and raise productivity in manufacturing directly when integrated into production locally. They can also contribute to the building of deeper levels of technological capabilities by local firms. Firms in these countries used imitation through reverse engineering of imported products to stimulate technological learning (as outlined clearly in Kim (1997)). Imitation has, for countries in the early stages of technological development, traditionally represented a key channel of "informal" technology transfer that is not mediated through market channels.

However, countries that have benefited from technology transfer through trade invariably had in place either an explicit industrial policy to creatively promote it by ensuring that the use of tariffs and incentives rewarded the best performers and penalized weak performers. In fact, Fransman (1986) went on to argue that tariffs were removed whenever national firms had successfully caught up with competitors. Simply opening up the international trading system without building domestic capabilities has generally led to the destruction of domestic capabilities (Lall, 2001). Indeed, it is under such circumstances that developing countries may face intensified commodity dependence and either stagnant industrialization or deindustrialization along with deteriorating terms of trade.[11] Countries that developed strong national capabilities, such as the Republic of Korea and Singapore, have managed to check the problem of falling terms of trade. Similar but scattered examples of a reversal in the terms of exchange can also be found in particular industries in other countries. For example, Brazil, Argentina, Chile, China, India and Malaysia have enjoyed favourable prices in the items of pulp and paper (Figueiredo, 2008), automobiles (Bernat, 2008), salmon (Vidal, 2008),[12] telecommunication products (Rasiah, Zhang and Kong, 2012) and palm oil (Rasiah, 2006) from time to time.

[11] Prebisch (1950) and Singer (1950) posited the famous Prebisch-Singer thesis that developing countries were facing a trend fall in the terms of trade because of their specialization in primary commodities and the developed countries in industrial goods. Singer subsequently extended this to include light manufactured goods in the developing countries through the Singer-Sarker thesis (Singer and Sarker, 1991).

[12] See also UNIDO (2009).

Human capital transfer and knowledge circulation

Technology transfers to support technological catch-up at developing sites have also benefited from flows of knowledge through human capital transfers, and brain circulation. The return of the diaspora from Silicon Valley in the United States of America to the Republic of Korea, and India played a major role in the transformation of engineering-intensive firms such as integrated circuits and software (Saxenian, 2006). These countries have also benefited from knowledge circulation through internet-connected and other contact networks with human capital residing in Silicon Valley (Saxenian and Hsu, 2001). Apart from economies facing poor labour, resource, infrastructure and domestic market endowments, most other developing economies that are secure and stable enjoy at least some amount of bargaining position to be able to frame strategies to appropriate knowledge spillovers from human capital located abroad.

Institutions and organizations

Institution building – the sine qua non for sustained growth and structural change –can only be achieved when governments create and coordinate the incentives through selective but appropriate interventions. Host governments have a big responsibility to drive institutional change to facilitate learning and innovation domestically (Nelson and Winter, 1982; Rasiah, 1988). Kaldor (1967), Singh (1989), Chang (2002), Reinert (2007) and UNCTAD (2007) argue that developing economies should shift the focus of growth to industrialization to drive growth through economic activities subject to increasing rather than diminishing returns.

The development of human capital nationally is vital to enable technological development and critical for absorbing technology that is transferred. As firms mature through the technology trajectory, their demand for human capital will first include the hiring of technicians and engineers to undertake problem solving, adapt and modify existing equipment and layouts, and eventually undertake R&D activities. Hence, many governments have, through policy interventions, sought to systematically raise the enrolment of pupils in primary, secondary and tertiary education. The East Asian economies of Japan, the Republic of Korea and Taiwan Province of China emphasized strongly technical and engineering education and training (Vogel, 1991).

Whether through national meso organizations (for example, R&D institutes, universities, technology transfer offices or government agencies for training or standards setting) and firms, or through working experience gained from TNCs,[13] or a combination of them, institutions and institutional change have been critical in the successful transfer of technology to latecomer local firms in developing countries. The systemic nature of knowledge creation and flows was demonstrated by Marshall (1890),[14] and Nelson and Winter (1982). The specificities of different industries, varying initial structural conditions and differences in the timing of catch-up have also led to different institutional roles, such as the type of incentive framework used to promote technological upgrading (Rasiah, 1988, 1996, 2002; Hobday, 1995, Malerba, 1992; Malerba, Nelson, Orsenigo and Winter, 2001; Nelson, 1993; Rasiah, Kong, Lin and Song, 2012). Knowledge flows from interaction between workers, and from the movement of human capital, is important to drive systemic synergies. Mature firms in open integrated clusters gain new ideas to support continuous organizational change as old employees are replaced to make way for fresh ones, while new firms benefit from the released entrepreneurial and technical human capital to start new firms (Best, 2001; Rasiah, 1987). Rasiah (1987, 1994), Saxenian (1994) and Best (2001) document the development and movement of human capital, which has supported new firm creation in Penang, Malaysia and Silicon Valley, United States respectively.

Firm-level technological upgrading often relies extensively on knowledge accumulation stimulated by institutional change. Institutional

13 To support their own self-expansion plans, TNCs from abroad facing attractive incentives and grants have relocated the high technology activities of wafer fabrication and design of integrated circuits manufacturing to Singapore (Rasiah and Yap, 2012).

14 Marshall (1920) observed the virtually costless flows of knowledge through interactions between workers in a cluster of firms. This knowledge flow can be viewed as systemic as it flows through the system.

change not only requires the introduction and enforcement of the appropriate institutions, but also of the intermediary organizations essential to solve collective action problems among firms.[15]

However, unlike the works of many neoclassical analysts, who tend to reduce technology to an exogenous black box and assume smooth and easy absorption of knowledge or technology, knowledge appropriation requires considerable effort by recipients, as argued by Lall (1992). The historical sequence of the development of technological capabilities through industrial policy started in England when Henry VII imposed taxes on exports of wool in 1485 (Reinert, 2007). A series of industrial policies helped the United States, Germany, Sweden, Japan and the Republic of Korea and to achieve technological superiority in industries characterized by increasing returns to scale. Coase (1937, 1991) and North (1990, 1993) discuss the significance of institutions in production allocation and capitalist development and identify markets (and market mechanisms) as the superior institution in the process.

Using the experience of Japan, Freeman (1989) demonstrated that international flows of knowledge from developed to developing countries follow a sequential movement in stages from imports to adaptation, assimilation and then innovation that countries typically pass through in moving up the technology ladder. The Marshallian view of the systemic nature of knowledge flows remains critical in understanding the generation and diffusion of technological spillovers. However, institutions other than markets, such as investment by governments, and trust relationships supported by particular sociocultural and economic groups and intermediary organizations, have been no less important in technological catch-up (Rasiah, 2007; Nelson, 2008). The argument is made by Hirschman (1970) and Rasiah (1995, 2008) that host country policymakers should examine the potential for translating *potential* into *real* spillovers, rather than leaving it to market forces. It can be argued that whereas market-based approaches only allow gradual catching up, the evolutionary and heterodox approaches put forward by Hisrchman (1958), Gerschenkron (1962) and Rasiah (1995), among others, encourage faster catching up.

Significant roles of government, going beyond just resolving market failures, and of markets and other institutions together helped alter the rules of the game to facilitate technology transfer in successful instances of technological catch-up (Rasiah, 1995). The Government of the Republic of Korea ensured that performance standards applied to firms drove technological catching up by Samsung in electronics, Hyundai in shipbuilding and automobiles and Posco in steel in the 1970s (Amsden, 1989; Kim, 1997). The Government also utilized expensive loans from abroad to shield successful chaebols from the destabilization caused by a four-fold rise in oil prices from 1973–1975. In Taiwan Province of China, the Industrial Technical Research Institute (ITRI) created by the Government in 1974 was instrumental in driving technological catch-up, inter alia, in information hardware, machinery and plastics (Amsden, 1985; Fransman, 1986). The Government financed the acquisition of Radio Company of America (RCA) in 1979 (Rasiah and Lin, 2005) and the founding of the joint venture company of Taiwan Semiconductor Manufacturing Corporation (TSMC) with Philips in 1987, which by the end of 2000 had become the world's leading contract manufacturer of fabricated wafers. Using its de-verticalized framework, TSMC also began fabricating microprocessors for Intel in 2009 (Rasiah, Kong, Lin and Song, 2012).

Clusters as a tool to promote technology transfer

Clusters refer to spatial agglomerations of firms that are connected to one another in production relationships, and the meso organizations that play the important role of solving collective action problems. They represent a tool that has been used extensively by policymakers seeking to promote technology transfer and industrial development. Evidence shows that technology transfer and technological catch-up are stronger and can spread to more firms when firms are located in integrated clusters (Best, 2001; Pietrobelli and Rabellotti, 2007).[16] Governments

15 The provision of public goods (e.g. knowledge) often raises collective action problems, which refers to a situation in which a group of economic agents would all benefit from a certain action made collectively, rather than individually. For example, several economic agents will benefit from a university or a R&D laboratory, and hence, its access will benefit society if its ownership is left open rather than confined to one agent.

16 Integrated clusters refer to spatial agglomerations that are not only populated with all of the components of a cluster (firms and organizations), but also enjoy strong connections and coordination between each other.

can create or strengthen the institutions and the infrastructure to promote agglomeration effects and increase the connectivity between firms and meso organizations (Rasiah, 2007), as witnessed in the case of electronics in Taiwan Province of China.

Given the problems of information imperfections between government and firms, intermediary organizations such as chambers of commerce and training institutions are often established to resolve the collective action problems faced by individual firms. The establishment of various intermediary organizations and meso organizations can be an important form of government support. The infrastructure needed for production is also often a critical element of weakness in the innovation system in developing countries where policy action can help. Infrastructure includes both the basic infrastructure (such as electricity, transport (roads, ports), water and ICT infrastructure) and the technology or high-technology infrastructure (including R&D laboratory facilities and R&D services). Clusters can be a useful tool for providing high-quality infrastructure and institutional support in a specific location in countries where these represent a significant challenge. Cluster policy is widely used by countries of all income levels across the world.

Several elements are vital for the development of competitive clusters.[17] They include interdependent relationships that are driven by the discipline of the market, participation of government when public goods are involved and the building of trust and loyalty to extract social commitment from the people involved (from firms, meso organizations and government). Stakeholder coordination (for example, through industry, government, consumer and labour coordination councils) often helps to promote the building of social capital.

A lack of human capital or the institutions necessary to stimulate innovation and competitiveness have often undermined the capacity of clusters to support long-term differentiation and the division of labour, which are also the prime reasons for the stagnation that has characterized industrial clusters in many developing economies. Indeed, the cluster in Penang, Malaysia, has failed to drive cluster synergies and enable local firms to reach the technology frontier because of serious shortages in human capital and knowledge-creating R&D organizations (Rasiah, 2010). Attempts to implement catching-up strategies should start with the mapping of firms, institutions, policy frameworks and their integration with markets (both global and local), and to identify the existing and potential drivers of industrial dynamism in particular regions or locations.

Dynamic clusters are characterized by the creation of innovation (Best, 2001; Rasiah and Vinanchiarachi, 2012). However, the driving force of innovation in a dynamic location is essentially the interdependent and interactive flows of knowledge and information among people, enterprises and meso organizations within the cluster. Coordination between the critical economic and technological agents across value chains who are needed in order to turn ideas into processes, products or services in the marketplace is important for success. Integrated connections between micro agents (firms and individuals), meso organizations (intermediary bodies solving collective action problems) and macro institutions (rules of the game), rather than simply the geographical co-location of firms, is vital to drive knowledge flows among agents within the cluster (Lundvall, 1992; Rasiah, 1996; Mytelka, 2000). In dynamic clusters such as Silicon Valley and Route 128 in Boston, United States, innovations evolve from a complex set of interrelationships among these actors, including a range of enterprises, universities and research institutes. The role of user–producer interactions in driving learning and innovation was articulated lucidly by Lundvall (1992) and Archibugi and Lundvall (2002). The execution and appropriation of these innovations, inter alia, expand the range of actors in dynamic clusters to include intermediary organizations such as suppliers, venture capitalists, property rights lawyers and marketing specialists.

Technology transfer and technological capabilities

Technology transfer is particularly important in terms of the contribution that it can make in building the technological capabilities of countries and firms. Technological capabilities refer to the ability of firms (or other actors) to identify, choose, access, learn, understand and use technologies and create new technologies.

[17] These refer to integrated and innovative clusters that support internationally competitive firms.

Evaluating the impact of technology transfer on capabilities is a difficult exercise, given the problematic nature of measuring technological capabilities. Agreeing an operational definition of technological capabilities is in itself already a challenge. There are a number of indices that have been created to provide indicators of technological capabilities at the national level, but few at the industry or firm level. Among national level indices, the UNCTAD innovation capability index is based on two subindices measuring human capital and technological activity, respectively. The World Bank knowledge economy index is based on measures of human capital, innovation system development and ICT development. INSEAD, Cornell University and the WIPO global innovation index is based on two subindices measuring innovation input and innovation output, respectively. The World Economic Forum, UNIDO, UNDP, OECD and the European Commission have all created synthetic indices measuring competitiveness, innovation capabilities and/or technological capabilities. More recently, Castellacci (2011) and Castellacci and Natera (2013) created indices to measure innovative capability and absorptive capacity in an attempt to measure the drivers of national innovation systems over time. These indices have all been used to make comparisons across countries at a macro, national level and serve a useful purpose in benchmarking exercises.

Turning to the firm or industry level, there are many ways of classifying capabilities. Business experts view management capabilities (and with that its components of entrepreneurship, personnel, accounting, marketing, engineering and quality) as key to establishing competitiveness (see, for example, Teece, 2009). While such classifications are useful, they extend in an overlapping way so much so that they often include capabilities that are not technological.

Firms build technological capabilities based on tangible and intangible assets that they acquire or develop themselves. The specific categories, phases and processes of technological change were analysed lucidly by Rosenberg (1976). Rosenberg and Frischtak (1985) defined technological capability as a process of accumulating technical knowledge or a process of organizational learning. Dahlman, Ross-Larson and Westphal (1987) emphasized the underlying concept of capability deepening as firms move from technology-using production capabilities to innovation-driving production capabilities. The sequence of capabilities they developed – running from production capability through investment capability to innovation capability became the basis of the taxonomies of technological capabilities developed by Bell (1987) and Lall (1992). Kim (1997) developed the sequence of capabilities moving from duplicative imitation to creative imitation and then to innovation capabilities. Hobday (1995), Mathews and Cho (2000), Mathews (2002) and Lee (2005) all outlined possible patterns in the development of firm level capabilities.

In analysing the contribution that technology transfers can make to building technological capabilities, Bell (1986) grouped technology flows into three conceptual categories. The first category (Flow A) consisted of capital goods and technological, engineering and management services. The second (Flow B) consisted of the skills and know-how to operate and maintain the newly established production technology. The third (Flow C) consisted of the knowledge and expertise to implement technical change, or the "know-why". In this framework, the first type leads to an improvement in production capability, the second contributes to technological capability at the basic and routine levels, and the third enables the firm to generate dynamic technical and organizational change. He thus identified three different levels of technological capabilities that can be strengthened by technology transfers.

Lall (1992) outlined a functional categorization of technological capabilities based on the task facing a manufacturing firm. He divided the capabilities associated with the tasks into two groups: investment capabilities and production capabilities. These were further subdivided into three levels of capabilities: a basic level consisting of simple and experience-based capabilities; an intermediate level consisting of adaptive and duplicative but research-based capabilities; and an advanced level consisting of innovative and risky but strongly research-based activities.

Wei (1995) integrated Lall's functional categories with Bell's technology flow classification. He concluded, first, that not all technology flows generate technological capability, and second, that linkages with national supplier and other firms in an economy are critical for enhancing capabilities. Rasiah (2009, 2010) drew on these contributions to focus on technological capabilities of firms that undertake production activities, establishing in the process a typology of capabilities based on the depth and trajectory of knowledge among firms. This framework allowed the measurement of three different types of embodied technological capability: human resources, process technology and product technology so as to facilitate the estimation of the overall technological capability (TC) of a firm, which is also important to examine the influence of export, ownership and firm-size on technology. Annex 1 illustrates an effort to evaluate the level of technological capabilities attained by firms in HSIP, and Qiaotou, China, utilizing this framework.

Demand–supply influences from buyers in domestic and export markets and the embedding institutions and organizations play a critical role in driving technological upgrading in firms (Lundvall, 1992; Nelson, 2008). While it is important to examine the supporting strength of the embedding environment, it is also important to evaluate the level of technological activity of firms located in particular locations. As pointed out by Nelson (2008), the framing of typologies to evaluate technological capabilities and upgrading would require an inductive understanding of firms in particular locations – which is often defined by location, time and industry-type specificities. Only when firms enjoy technological upgrading will they be able to sustain growth in value added, skilled jobs and wages.

On the basis of this framework, the next section investigates four cases of technology transfer to identify the role that technology transfer played in strengthening local firm capabilities and building competitive local industries.

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Chapter 2. The cases of integrated circuits in Taiwan Province of China and buttons in Qiaotou, China

A. Technology transfer and integrated circuits production at Hsinchu Science-Based Industrial Park, Taiwan Province of China

The case of electronics in Taiwan Province of China represents a notable success story in leveraging the transfer of technology to create local innovation and stimulate industrial development by local SMEs. It provides a clear example where policy measures aimed at creating a dynamic cluster to support rapid technological upgrading among local SMEs achieved a high degree of success. The Hsinchu Science-Based Industrial Park (HSIP) is arguably the most successful developing country example of a dynamic cluster of firms with high intensity of connections and coordination between firms and meso organizations (ITRI and ERSO) that have evolved through a wide mix of smoothly networked institutions. It is also a location where new firms have scaled the heights of technological upgrading to reach the global technology frontier in integrated circuits (Rasiah and Lin, 2005).

The first integrated circuit firms to operate in Taiwan Province of China were United States firms such as RCA, which started assembly activities in Kaoshiung in 1966. Afterwards, a few Japanese firms followed this move to assemble integrated circuits in Taiwan Province of China. However, the successful technology transfer and technological catch-up experience of Taiwan Province of China owes much to efforts by the national authorities to promote the industry for strategic reasons.

A national plan was launched in 1975 to support the creation and upgrading of national firms in integrated circuits and complementary products (e.g. computers and telecommunications equipment) by the year 2000. Targeting strategies to stimulate industrial upgrading from low to high value added activities, but recognizing that firms then were too small to internalize technological upgrading activities on their own (Xu, 2000), the Taiwanese authorities formulated a policy to launch the Industrial Technical Research Institute (ITRI) in 1973 (Lin, 2003). ITRI was established in 1973 in order to bring foreign technology to Taiwan Province of China. The Electronics Industry Research Centre – which became the Electronics Research and Service Organization (ERSO) in 1979 – was established in 1974 as part of ITRI and was allocated the role to undertake R&D on electronics. HSIP was established in 1980.

The Technical Advisory Committee (TAC), which was comprised of Taiwanese who had gained considerable experiential knowledge working in foreign TNCs, became important advisers influencing official policy on technology transfer. It is this group that recommended the formulation of ITRI, and ERSO as one of the strategic laboratories, to support technology development and technology transfer to national firms in Taiwan Province of China. United Microelectronic Company (UMC) was the first integrated-circuit foundry to be launched through ERSO. UMC was formally established in 1980 but its origins began as an incubator at ERSO in 1976. The semiconductor division of RCA was acquired in 1978 for purposes of technology transfer as well as market access. UMC was also the first firm to start fabrication at Hsinchu Science-Based Industrial Park (HSIP) in 1980. HSIP became the focal point of most integrated-circuit designing, manufacturing and production activities in Taiwan Province of China. Whereas UMC started as a fully government-owned firm, it was later equitized and sold to private shareholders.

Aggressive government promotion drove rapid technological catch-up and the birth and growth of high-technology firms in integrated circuits production. Government plans to stimulate upgrading of firms in the integrated circuit industry to the technology frontier were formulated from 1975. The process started with strong government expenditure in R&D activities, which was replaced gradually by private participation (Mathews, 1997, 2005; Mathews and Cho, 2000; Lin, 2003; Tsai and Cheng, 2006). The public sector financed integrated circuit R&D from 1975 to 1984, with private firms becoming important following the listing of UMC on the stock market in 1985 (Cheng, 2006). Technology transfer began originally with the appropriation of knowhow from RCA over the period 1975–1979. Following the establishment of the pilot integrated-circuit plant, ERSO sent the first batch of 19 engineers to RCA for technical training in April 1976.[18] Technology transfer from RCA to ERSO occurred through two major channels:

- ERSO acquired manufacturing technology, know-how on how to operate integrated circuit businesses, from management of plant, material and inventory, to monitoring customer taste and demands[19]
- ERSO acquired design and R&D from RCA, thereby making it possible to introduce Taiwanese engineers to the real, but complex, aspects of high technology, as well as markets to sell to. ERSO spun out United Microelectronics Company (UMC) from RCA in 1980. A number of previous buyers of RCA successfully shifted their purchases to UMC. Indeed, the introduction to design and R&D from RCA gave a huge leap to the technological capabilities of ERSO.

Technology transfer from RCA to ERSO began in October 1976 when the first batch of engineers was sent to receive technical training to support the construction of the pilot plant to manufacture integrated circuit chips at ERSO (Lin, 2009). The technology transfer process was also strongly aided by the ingenious effort by the Taiwanese to decompose further integrated circuit production to include independent wafer fabrication plants. Box 1 shows the stages involved in the production of integrated circuits by Taiwanese firms. Being a risky and uncertain initiative, ITRI faced considerable challenges in the pursuit of its goal of moving Taiwanese firms to the integrated-circuit technology frontier. After the plant was completed, the engineers who were trained at RCA began to participate in actual operations in October 1977.

The pilot plant manufactured its first manufactured wafers that were supplied for assembly in electronics watches. As chip manufacturing expanded, they began to face marketing problems as no one in the pilot plant was trained to handle marketing and product sales. In fact, at this time a Hong Kong, China businessman helped sell 10,000 pieces of integrated-circuit chips to electronics watchmakers. It was only after this experience that ERSO integrated sales and marketing with manufacturing. The focus then shifted to increasing yields from 50 per cent to 60 per cent and to 70 per cent of installed capacities, which exceeded the yields achieved by RCA. Clearly at this stage of creative destruction, ERSO's introduction of best practices was already transforming production to a higher level than what was transferred from the acquisition of RCA. Kim (1997) referred to such creative destruction effects as creative duplication that required frequent changes to organizational structures, layouts, processes and machinery and equipment. Scale is critical in the production of integrated circuit wafers, assembly and testing. Hence, accessing export markets through the establishment of alliances with buyers abroad played a major role in the origin of national integrated circuit firms in Taiwan Province of China.

Besides the members of TAC, it is worth mentioning the transfer of knowledge of a few Taiwanese from the United States who contributed to the first integrated-circuit project. In 1974, C.T. Shih and T.Y. Yang who had just got their PhD degrees in semiconductors in the United States, responded to the advertisement in a Taiwan Province of China newspaper seeking integrated circuit project engineers. When they returned to Taiwan Province of China to participate in the project, they also wrote to their department mate in Princeton University, C.C. Chang who then returned to Taiwan Province of China to join the ERSO project after he graduated (Lin, 2009). In such high-technology fields, the development of specialized knowledge through the pursuit of graduate degrees in semiconductors and related fields proved crucial, and this channel of knowledge acquisition and transfer also led to the development of new products initially through scaling activities in the incubators at ERSO,[20] and subsequently strong links between ERSO, universities and firms.

[18] According to the contract obligations, RCA agreed to offer training amounting to 353 man-months and to 53 persons (Lin, 2009).

[19] The head of the accounting department of ERSO went along to RCA to acquire knowledge on how RCA built up its accounting system (Lin, 2009).

[20] New "species" of products are referred to here as a group of new but related products that are generated through the use of similar technologies, which are produced from specializing in the economies of scope.

The return of a few Taiwanese experts in the field of integrated circuits and related technologies provided the snowballing effect to attract more Taiwanese to return. This process was not easy as in the 1970s, Taiwan's economic development was still backward, and the superior infrastructure of the United States was always very appealing to the majority of Taiwanese. Most ambitious integrated-circuit experts would have stayed in the United States, as the industry was still in its infancy in Taiwan Province of China when the leading companies were still in the United States at that time.[21] Hence, the return of the three doctoral graduates from Princeton University in the United States really boosted the morale of all staff in the project. Interviews with some older members of the experts who returned to work in ERSO in 1975–79 showed that they were also culturally committed to helping out with their aging parents who had educated them.[22] Although accommodation and English-based schooling were important to facilitate the return of the diaspora, the role of the Taiwanese authorities in granting equal standing to all Taiwanese returning from abroad was also important.[23]

A. 1. Large-scale integrated-circuits projects initiated by the Taiwanese authorities

The Taiwanese authorities launched four large-scale integrated-circuit projects. The first project was implemented over the period 1975–79 through the fusing of R&D knowledge developed in ERSO and the technology that was successfully transferred from RCA. ERSO's second major project lasted over the period 1979–83, when the major focus was on the development of the computer industry, which had a direct bearing on the integrated circuit industry, as it became its leading user. As the miniaturization of integrated circuits globally accelerated, the authorities launched the very large-scale integration (VLSI) project to evolve integrated circuit capabilities to meet the demands of cutting edge computers over the period 1983–90. The third phase culminated in the opening of the Taiwan Semiconductor Manufacturing Corporation (TSMC), which started as a merger with Phillips in 1987. TSMC enjoyed government equity in the early years but has since been sold to private owners. Morris Chang masterminded the opening and the development of this firm (Lin, 2003).

Taiwan Mask and Yi-Wei Corporation were incubated at HSIP in 1987. In the penultimate phase of their development, the Taiwanese authorities focused on the development of submicron chips over the period 1990–94, which resulted in the creation, again via incubation at HSIP, of the firm Vanguard. Vanguard was the first Taiwanese firm to make 8″ wafers. The final phase of 1994–2000 was targeted at the development of the advanced submicron project. This project did not take off, as private firms such as TSMC and Vanguard had by then already developed their own technologies to advance to 12″ wafer fabrication (Lin, 2009). ERSO initiated these projects to advance integrated circuit technology so as to stimulate the movement of Taiwanese firms to the technology frontier. Unlike the processes of catching up in Singapore and Malaysia, where assembly and testing activities initiated their domestic integrated circuit industries, in Taiwan Province of China, assembly and test operations were developed after fabrication and designing were introduced under the ERSO plan. ASE is one of several national assembly and test plants that have expanded operations successfully.

The HSIP model was unique in its capacity to stimulate the co-evolution of technologies. A wide range of technologies evolved through cross-flows of knowledge to spearhead the development of new products that integrated the electronics of control, sophisticated materials and metal alloys, neurology, ergonomics and machinery. Within electronics, the Taiwanese authorities initiated complementary large-scale projects in computer and peripheral production – e.g. the Computer Project I (1979–1983), Computer Project II (1983–1987) and Computer and Telecommunication Project (1987–1991). These projects have advanced computer and peripheral technology,

21 Mr. Shih eventually became the president of ITRI and in 2009 was the Dean of the School of Technology Management in TsinghuaUniversity in Taiwan Province of China. Mr. D.Y. Yang was the Chair of Winbond Semiconductor International. Mr. C.C. Chang was the head of ERSO, and in 2009 was Chair of Vanguard International (Lin, 2009). All of the 19 engineers who went to RCA in the 1970s have had high achievements in their career development (Lin, 2009).

22 Interview conducted on 12 September 2009 in Hsinchu City.

23 Ibid.

and thus laid the foundations for the development of the computer industry in Taiwan Province of China. The technological capabilities developed from projects have contributed enormously to the development of the computer industry, as all the brand-name computer companies have subcontracted the production of their computers to Taiwanese computer companies (Lin, 2001).

Of the concurrently implemented integrated circuit projects, ITRI spun off United Microelectronics Corporation (UMC) in 1980, Taiwan Semiconductor Manufacturing Corporation (TSMC), Taiwan Mask and Yi-Wei Corporation in 1987, and Vanguard International in 1994. While these firms' operations represented clear leaps in the technology of the integrated circuit industry of Taiwan Province of China, numerous small and medium-sized designing firms were also incubated at HSIP and have generated significant amounts of value added.

The technology of private integrated circuit firms in Taiwan Province of China was until 1984 almost wholly transferred from ERSO. UMC benefited from a wholesale transfer of production and management technology over the period 1979–82 from ERSO. TSMC enjoyed the same transfer in 1986–87. ERSO also transferred integrated circuit design to Syntek Semiconductor (1983), Holtek Semiconductor Corporation (1983), Proton (1985), Advanced Device Technology (1986), Hualon Microelectronics (1987), Winbond (1987) and Silicon Integrated Systems (SIS) Corporation (1988) (Huang, 2006). ERSO developed technologies jointly with private firms only from about 1989 – such as VGA with Winbond and 50V CMOS FET with Holtek Semiconductor Corporation. Huang (2006) noted that around 75 per cent of the optoelectronics technology of Taiwanese integrated circuit firms in the late 1990s was transferred from ITRI. Another key feature of the integrated circuit industry of Taiwan Province of China is the co-evolution of knowledge from other laboratories such as in mechanical and equipment engineering, materials and chemicals that helped complement the development of new products.

Although TSMC acquired its initial technological capability through the ITRI VLSI Project, the Chair of TSMC (Morris Chang, a returning diaspora), introduced a new business model where firms specialized horizontally in wafer fabrication undertaking R&D and capital-intensive production. TSMC specializes in integrated circuit chip fabrication based on customers' designs without using its own design. TSMC was the first horizontally integrated integrated circuit foundry in the world to specialize only in fabrication (Rasiah and Lin, 2005). Prior to the establishment of TSMC, integrated circuit companies were all vertically integrated, with most firms engaged in R&D, design, wafer fabrication, and assembly and test operations. Some integrated circuit firms emerged to undertake only assembly and test operations of dated technologies. The establishment of TSMC led to the decomposition of integrated circuit production to its independent stages so that independent integrated circuit design companies and wafer fabrication plants began to emerge in computer-based integrated circuit products.[24]

In the new, decentralized formation of integrated circuit firms, design and R&D became the most knowledge-intensive parts of the production process. Whereas research generated knowledge – defined both in property rights terms and as simply knowledge – those commercialized ended up as money generating products. Also, whereas R&D was risky and uncertain as new discoveries are not necessarily commercial value creating, design focused on scaling and commercial value-creating prototypes. Hence, design became the most lucrative stage in the integrated circuit value chain. It was also the least costly, most flexible and agile in responding to changes in market demand. Wafer fabrication became the most capital intensive and costly, while assembly and test became the most labour intensive and the second most costly stages in the integrated circuit value chain. However, the appropriation of high value adding profits in design often required the presence of the anchor stage[25] – i.e. wafer fabrication. Hence, its emergence in Taiwan Province of China created the opportunity for the mushrooming of design firms in the country. Independent integrated circuit design companies

[24] See annex 1 for an outline of the stages in the value chain for integrated circuit manufacturing.

[25] Wafer fabrication is the anchor stage in integrated circuit production because it is in the fabrication of wafers that the circuit implant of storage, static and dynamic functions of the chip is carried out. It is also the most capital intensive, so other firms in the integrated circuit value chain connect strongly with fabrication plants.

can focus on integrated circuit chip design and fabrication. Foundries such as TSMC and UMC will fabricate the integrated circuit wafers for them. In some product lines, particularly in logic chips, TSMC and UMC have also contributed significantly to the development of integrated circuit design, though its fabrication plant continues to specialize horizontally.[26]

A. 2. Hsinchu Science-Based Industrial Park

To facilitate the development of high-technology industries in Taiwan Province of China, the Taiwanese authorities established HSIP in 1980 to host high-technology firms there. UMC was the first company to locate in HSIP. HSIP provides incentives such as tax holidays, tax reduction and subsidized land to companies in six high-technology industries, namely, integrated circuits, telecommunications, computers and peripherals, bio-technology, precision machinery and optoelectronics. The large-scale projects initiated by ITRI and its various spin-offs have made HSIP the centre of the information and communications technology (ICT) industries in Taiwan Province of China, and have created a large number of job opportunities.

The development of HSIP was relatively slow until 1987. Its rapid growth started after 1987. The number of employees and sales volumes generated at HSIP increased by almost 50 per cent and 61.8 per cent, respectively, from 1986 to 1987 (table 1). At this time, a large number of returning diaspora started their own businesses in HSIP. Many set up their own integrated circuit design houses after TSMC was established in 1987. This trend of returning diaspora starting businesses escalated further after 1993. Integrated circuit design houses require less capital to start than highly capital-intensive wafer fabrication plants. The establishment of fabrication houses such as UMC, TSMC and Taiwan Mask facilitated the expansion of large numbers of low-capital but knowledge-intensive design houses at HSIP. A number of these design houses were started by Taiwanese enjoying tacit and experiential knowledge gained while working in Silicon Valley.[27] In a much celebrated example, the chair of Macronix, Mr. Ming-Qiu Wu, brought back 27 engineers and their families from

[26] Interview by author with the President of the Semiconductor Manufacturing Association of Taiwan Province of China conducted on 11 November 2008 in Hsinchu.

[27] Penrose (1959) referred to the acquisition or development of knowledge through experience as experiential knowledge. Although tacit knowledge has some elements of experiential knowledge it also comprises aspects of knowledge that are very specific to individuals – elements that no amount of experience can facilitate its acquisition (Polanyi, 1969).

Table 1 Employment and sales at HSIP, 1986–2008

Year	Employment	Sales ($ million)	Year	Employment	Sales ($ million)
1986	8 275	—	2000	102 775	29 803
1987	12 201	866	2001	96 293	19 619
1988	16 445	1 737	2002	98 616	20 454
1989	19 071	2 124	2003	101 763	24 973
1990	22 356	2.443	2004	113 329	32 552
1991	23 297	2 903	2005	114 836	30 765
1992	25 148	3 406	2006	121 762	34 503
1993	28 416	4 810	2007	129 512	34 829
1994	33 538	6 706	2008	130 577	31 964
1995	42 257	10 940	2009	132 174	na
1996	54 806	11 565	2010	139 416	na
1997	68 410	13 915	2011	148 714	na
1998	72 623	13 693	2012	151 282	na
1999	82 222	20 387			

Sources: Statistics Quarterly, Hsinchu Science-Based Industrial Park, March 2009; reproduced from Lin (2009) and HSIP Yearly Report from HSIP website http://www.sipa.gov.tw/english/home.jsp (accessed December 2013).

Table 2 Composition of firms at HSIP by industry, 2008

Industries	Approved firms		Paid-up capital		Employment	
	No	%	NT$million	%	No	%
Integrated circuits	202	45.4	773 344	68.3	77 634	60.2
Computer and peripherals	53	11.9	83 500	7.4	12,467	9.7
Telecommunication	45	10.1	26 818	2.4	7,798	6.0
Electro-optical	90	20.2	234 244	20.7	27 711	21.5
Precision machinery	26	5.8	8 169	0.7	2 141	1.7
Biotechnology	29	6.5	6 441	0.6	1 164	0.9
Subtotal	445	100	1 132 516	100	128 915	100
Others	5		1 994		307	
Total	450		1 134 510		129 222	

Source: Statistics Quarterly, Hsinchu Science-Based Industrial Park, March 2009; Reproduced from Lin (2009).

Silicon Valley to start Macronix in HSIP in 1989 (Lin, 2009). The technology transferred through the human capital drawn from United States firms in Silicon Valley helped to drive rapid growth at Macronix, with record sales of $1.5 billion in 2008.

The number of integrated circuit design houses in the HSIP rose from 30 in 1987 to 64 in 1993 and 250 in 2008. Taiwan Province of China had the second largest number of integrated circuit design houses in the world after the United States in 2008. This development would not have been possible without the returning diaspora. The majority of the 250 integrated circuit design houses are located in the HSIP, due to which the integrated circuit-related companies became the largest group, with a total number of 202 companies, accounting for 45.4 per cent of the all approved companies in HSIP (table 2).

A.3. Early stage development

Figure 1 shows the structure of meso organizations and knowledge flows, and the specific transfers of knowledge and technology from ITRI, foreign sources, and education, training and standards organizations to firms in HSIP. The Taiwanese authorities invested heavily in developing the absorptive capacity of its intermediary organizations and national firms by focusing on physical infrastructure, licensing and acquisition of knowledge from firms in related fields possessing superior knowledge, the creation and running of meso organizations focused on supporting R&D and design, and the development of human capital domestically and the relocation of nationals enjoying tacit and experiential knowledge from abroad (Vogel, 1991; Saxenian, 2001).

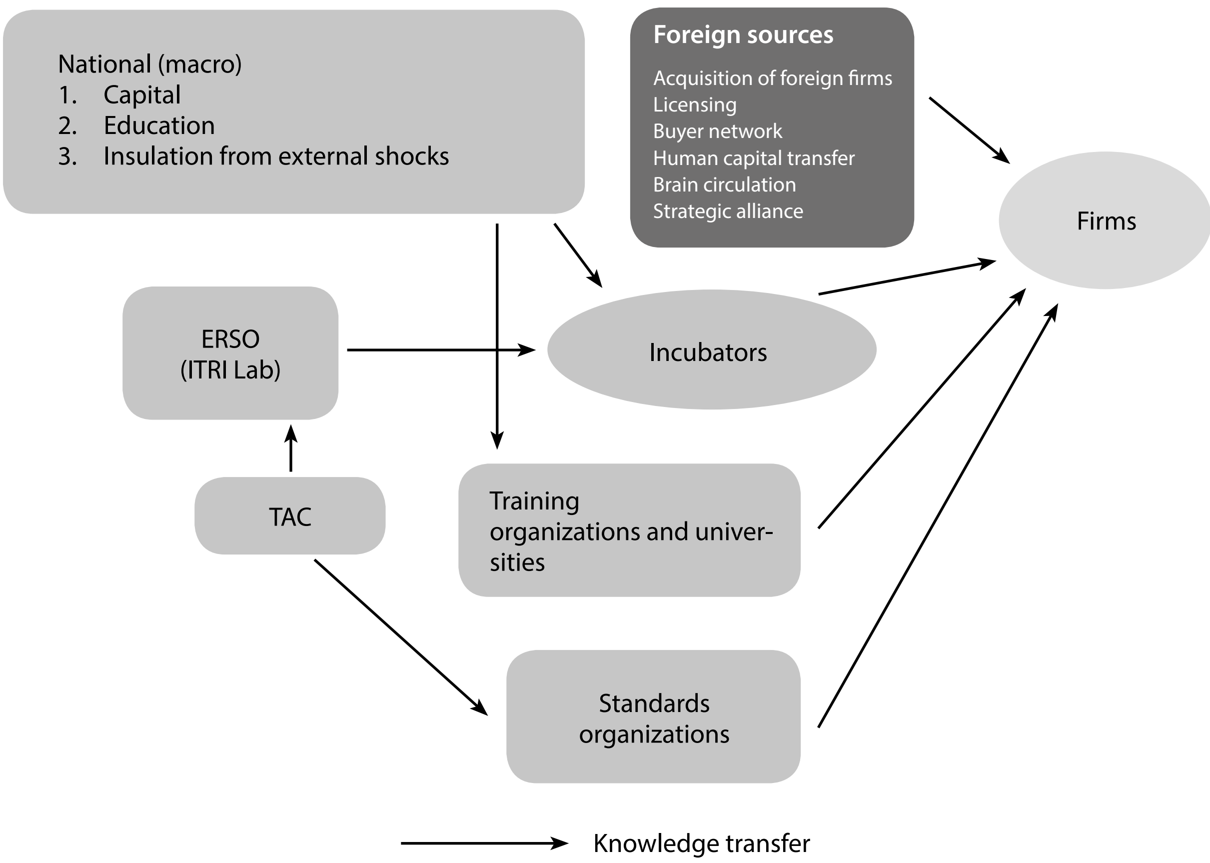
ERSO was launched in 1974 to play the pivotal role of coordinating the emergence of high tech national integrated circuit firms, and subsequently HSIP was formed in 1980 to act as the incubator bed to spawn national integrated circuit firms in high value adding, high technology activities. The Taiwanese authorities made most of the capital investment to develop the integrated circuit industry in the early phase of 1975–84. Private firms became increasingly important after 1985. The Technical Advisory Committee (TAC) was comprised mainly of Taiwanese experts who enjoyed frontier knowledge on the strategic industries earmarked for promotion by the Taiwanese authorities. Incubated firms were then graduated into private firms through the relocation of Taiwanese human capital enjoying both tacit and experiential knowledge working in frontier United States firms in the United States. TSMC, Vanguard and Winbond are among the frontier firms whose founding CEOs were relocated from firms in the

United States. The marriage of graduate education and tacit and experiential knowledge in high technology activities, production and marketing were central to support their roles as CEOs of these newly created high technology firms.

Standards and training organizations were also started to support the introduction of best practices in Taiwanese integrated circuit firms. Clearly, the transfer of knowledge from the United States (from the relocating diaspora and RCA) and the plants incubated from HSIP were the critical channels through which technology was transferred. Firms including UMC, Syntek Semiconductor, Advanced Device Technology, Hualon, TSMC, Winbond and Vanguard firms were launched. Whereas government plans were implemented through the ITRI laboratories, TAC played an influential advisory role with the members enjoying tacit knowledge that enabled the selection of strategic technologies to spawn and the linking of the newly emerging Taiwanese firms with major buyers.

Firms at HSIP grew rapidly from 1987 following the spread of their listing on stock markets. Whereas large, famous firms such as Acer enjoyed reputational and performance-based increases in share values, even new small firms such as Phison began to enjoy strong stock take up. Although Phison started as a firm incubated at HSIP in 2004 with equity capital of $900,000, its strong expansion led to its equity reaching almost $1 billion in 2009. This firm was started by a Malaysian whose master's thesis became the basis for the invention of the thumb drive. Confining its operations to design, the firm had 200 employees in 2008. Firms in the HSIP have much better chances of going public than those in traditional industries as high-technology firms in HSIP provided huge opportunities with very high monetary rewards (Saxenian, 2006).

Figure 1 Knowledge transfers to integrated circuit firms at HSIP, 2008



Source: the author.

A. 4. Maturity stage

The Taiwanese authorities had stopped direct policy funding of integrated circuit plants by 2000 as the objective of moving private firms to the technology frontier in the industry had been achieved. Ownership of firms was left to private capital, and R&D expenditure of private firms expanded sharply. They began to focus on refining the rules and coordination for incubator applicants and providing limited funds for R&D grant applicants from universities, intermediary R&D organizations and firms (figure 3). A two-way flow of information and influence in the governance of these organizations and firms has evolved since 2000. Institutions shape, and are then shaped, by the meso organizations and entrepreneurs located in in general and HSIP in particular.

The increased transfers of Taiwanese diaspora from universities, laboratories and firms in the United States to universities and R&D laboratories in HSIP, and more broadly in Taiwan Province of China, since the late 1980s, facilitated the specialization of R&D at Taiwanese universities that worked closely with ERSO. Taiwanese scientists in universities became eligible to seek R&D funds from the STP fund programme, which became effective only when the Government converted it into matching grants in 1983, and again from the late 1980s, when scientific publications became a critical measure of consideration for future applications.[28] The combination of transferred knowledge embodied in scientists working in Taiwanese universities, as well as knowledge evolved from talent developed domestically, helped generate powerful thrusts in knowledge flows that stimulated scientific publication by Taiwanese professors.

As Taiwanese universities became equipped with basic research facilities, ERSO began to concentrate fully on development faculties with a significant overlap with the activities of the scientists in the universities. However, as private design firms began to mushroom – from both a relocation of human capital from the United States and the graduation of students with MA and PhD degrees from local universities – design activity also began to expand rapidly in private firms in Taiwan Province of China. A notable example is the launching of Phison in 2004. At the time of the interview with its chief executive officer, Phua Kein Seng in 2009, Phison had expanded successfully to the point where it was supplying design services to major TNCs such as Toshiba and Signetics, with its capitalization amounting to almost $700 million.[29] Phison focussed on design, while fabrication took place in fabrication plants in Taiwan Province of China, and the assembly and testing of products were carried out in China. Fabrication plants, too, began to register a considerable number of patents as they invested extensively to develop state-of-the-art process- and material-based fabrication technologies. Hence, fabrication houses such as TSMC and UMC became major patent holders in the United States – far more than any other Taiwanese integrated circuit firms.

All Taiwanese integrated circuit firms that enjoyed assembly and test operations, such as ASE Semiconductor, were also engaged in cutting-edge, best practices in production technology, in close developmental collaboration with suppliers and buyers. Relational contracting through social and cultural bonds has been very important in ensuring that the demand–supply interface was stable. There were 11 national and 10 foreign integrated circuit assembly and test plants in Taiwan Province of China in 2010 (Rasiah and Yap, 2012).

Because Taiwanese integrated circuit firms in HSIP have reached the technology frontier, significant amounts of design operations are actually undertaken by specialized design firms. TSMC and UMC, for example, use designs produced by other firms in the cluster and from abroad to fabricate wafers. Because of the cohesive integration of the various actors in HSIP, and the agents located abroad, high levels of connectivity and coordination between them has increased their level of appropriation of process and product knowledge. Designing firms, most of which originated from the incubators, have often co-evolved a multiplicity of technologies because of the systemic synergies provided by such a unique integration of cross-flows of knowledge.

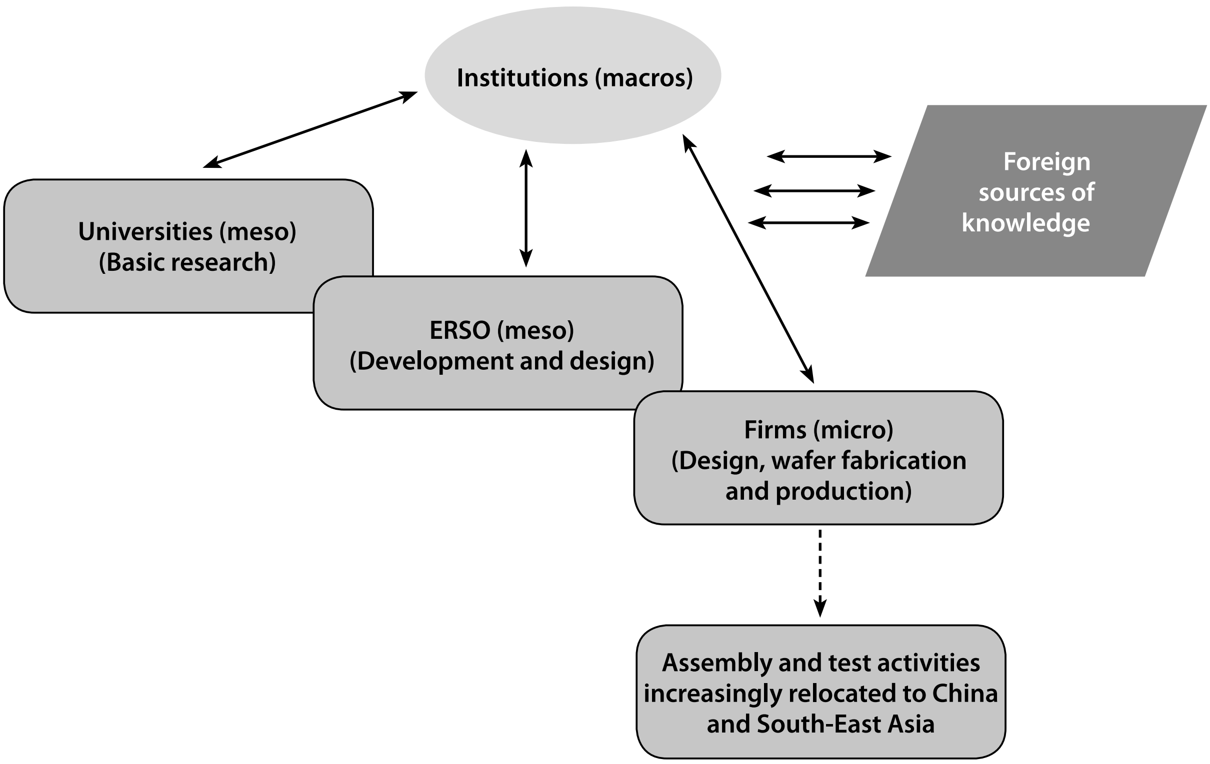
[28] Interview by the author with a senior official on 4 September 2009 in Hsinchu City.

[29] Interview by the author with Phua Kein Seng on 7 September 2009 in Hsinchu City.

The cross flows of knowledge from incubators located in different ITRI laboratories specializing in different strategic fields have made HSIP a fertile ground for the development of new species of products (figure 4). Proximity of the ITRI laboratories is important for effective interaction between the different laboratories, and between them and firms (Rasiah, Kong, Lin and Song, 2012). The fusion of scientific knowledge combining knowledge of the structure and behaviour of plants and animals with cutting-edge control and coordination from integrated circuits, state-of-the-art material specifications (e.g. carbon), metal alloys, machinery and central processing units has made HSIP a powerful producer of new species of products, which are displayed extensively at strategic exhibitions across the world. For example, among the hundreds of products innovated by HSIP firms is a fishing bait that uses technological knowledge involving radio-frequency-identification-(RFID) powered devices, zoology of the fish, environmental science and rubber that is used to attract and catch mature tuna fish.

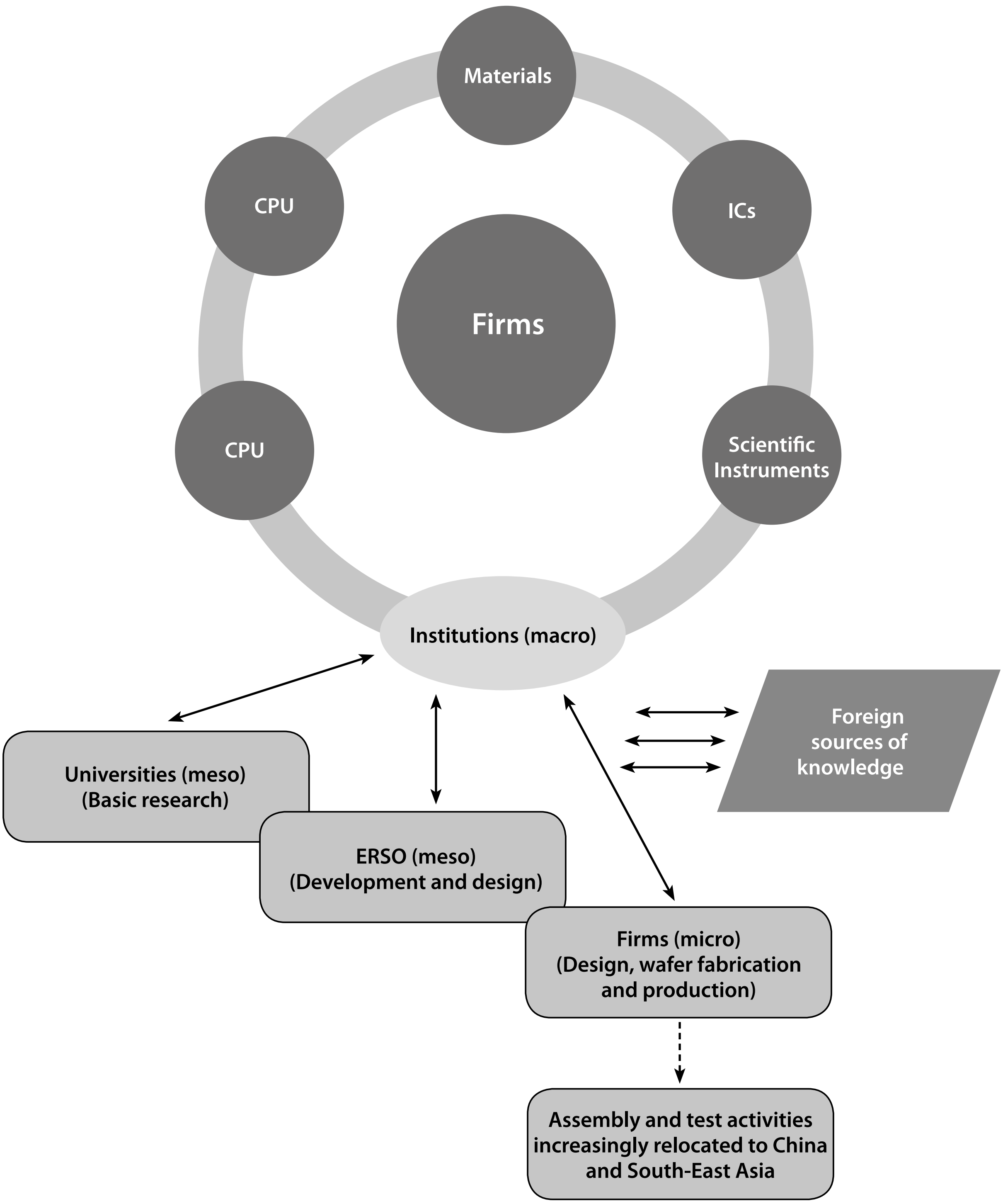
Clearly HSIP evolved to support the upgrading of national firms to the technology frontier in integrated circuit production, initially almost entirely relying on technology transfer from abroad and meso organizations targeted at generating knowledge. Significant knowledge transfers to integrated circuit firms came from the acquisition of foreign firms, technology licensing, and relocation and circulation of skilled people bearing tacit and experiential knowledge from working in TNCs operating at the technology frontier and R&D laboratories abroad. Knowledge developed in ERSO, and Taiwanese universities, as well as buyers and suppliers, have also been critical in the development of integrated circuit firms in the country. Finally, the co-evolution of knowledge from cross-flows of knowledge among complementary firms incubated at the different ITRI laboratories at HSIP was important in driving new product development. Hence, the

Figure 2 Macro, meso and micro interactions in the innovation system of integrated circuit firms at HSIP, 2011



Source: the author.

Figure 3 Technology co-evolution structure of HSIP, 2011



Source: the author.

Note: Cross-flows of knowledge drive integrated circuit design, which eventually leads to a wide range of newly created products.

Abbreviation: CPU – central processing unit.

dramatic movement of integrated circuit firms in Taiwan Province of China to the technology frontier is a consequence of the smooth coordination of institutions, meso organizations and firms as an institutional framework, with organizational anchors provided by ERSO and HSIP. The policy mechanism used by the Taiwanese authorities to stimulate technological catch-up included the imposition of discipline on grant recipients to prevent misuse of funds.

As integrated circuit firms moved to the technology frontier, the Taiwanese authorities reduced their role to just managing the HSIP and disbursing grants to support knowledge-based public goods. However, to prevent the dissipation of rents, they evolved a stringent vetting, monitoring and ex post appraisal mechanism to remove free riders and target funding to good performers. What was applied to the technology transfer agreements with foreign TNCs during the 1970s and 1980s were applied to national firms seeking R&D grants. The criteria of performance used ranged from scientific publications by university applicants, to patents and other proprietary rights in meso organizations, such as ERSO and firms, as well as the commercial value of output generated from the grants.

The consequences of successful learning and innovation in HSIP saw a massive transformation of the integrated circuit industry from a net importer of integrated circuits from abroad until the 1990s to a net exporter thereafter (table 3). Taiwan Province of China's integrated circuit exports and imports rose from $2.4 billion and $4.1 billion, respectively, in 1990 to $56.0 billion and $36.4 billion, respectively, in 2010. The country's share in global integrated circuit exports and imports rose from 2.4 per cent and 4.1 per cent, respectively, in 1990 to 11.7 per cent and 7.6 per cent, respectively, in 2010. The faster growth in exports helped to shift the trade balance from -25.7 per cent in 1990 to -4.3 per cent in 2000, and to 21.2 per cent in 2010. Also, among foundry fabrication houses, the revenue of TSMC and UMC rose from $8.2 billion and $3.3 billion, respectively, in 2005 to $13.3 billion and $3.8 billion, respectively, in 2010 (Gartner, 2011). When ranked against other integrated circuit firms, TSMC and UMC occupied third and eighteenth

Table 3 Taiwanese trade in integrated circuits, 1990, 2000 and 2010

	1990	2000	2010
Exports ($billions)	2.4	21.8	56.0
Share in global exports (percentage)	4.3	7.1	11.7
Imports ($billions)	4.1	23.7	36.4
Share in global imports (percentage)	7.4	7.7	7.6
Trade balance (exports minus imports/exports plus imports) (percentage)	(25.7)	(4.3)	21.2

Source: Computed from WTO (2011).

places, respectively, in 2010. Mediatek, another Taiwanese firm located at HSIP which also carried out integrated circuit design and production, ranked twentieth in revenue in 2010 once TSMC and UMC are included. This is a remarkable achievement and was only possible because of the smooth coordination between the macroinstitutions, the meso organizations and firms, which operate at the micro level.

B. Technology transfer and button manufacturing in Qiaotou, China

With production exceeding 60 per cent of the world's total production of buttons, and the emergence of frontier activities in design, materials technology and global exhibition centres, the Qiaotou cluster is a notable example of a competitive button cluster. This study aims to trace the transfer of the various sources of technology-based knowledge – both from abroad and from domestic sources – to button firms operating in Qiaotou.

The story of Qiaotou developing from the start of button production to becoming the centre for exhibitions displaying the latest and most sophisticated buttons by 2008 is a dramatic one that demonstrates the complex confluence of knowledge flows from abroad and from meso organizations that were deliberately created through interventions by authorities in Yongjia county in order to stimulate technological upgrading, and with it, income growth within the region. The actual origin of button sales in Qiaotou, however, had nothing to do with the Yongjia county authorities. The import of buttons began through local entrepreneurs selling imported buttons (as an important accessory to clothing and clothing products) to local garment manufacturers. It is the subsequent upgrading of Qiaotou through the supply of knowledge from meso organizations created by the Yongjia county government, and the effectiveness of coordination among those organizations and button firms, that stimulated the dynamic development of the cluster.

Qiaotou is located in the province of Zhejiang in Eastern China. Prior to the advent of its manufacturing in China, buttons were purchased from abroad. Italy was the main source of imports for clothing manufacturers in China. SMEs in Italy were world famous in introducing new button designs until the turn of the millennium. In 1978, two brothers began distributing buttons in Qiaotou, which were purchased from Huangyan in Zhejiang Province. This activity quickly grew into the opening of over 300 sales stalls by 1982 (Kong, 2008). Markets dominated the initial growth of the industry. Faced with rising costs, especially of raw materials such as polyester, and competition from emerging economies, Italian button producers responded to requests by Qiaotou's entrepreneurs to relocate the manufacturing segment of the button value chain over the period 1982–84, which was targeted at both the domestic and export markets. Button manufacturers in Qiaotou were mostly small, with the firms in the sample analysed in this paper (and reported on in annex 1, table A1.4) employing between 15 and 200 employees.[30]

Button market sales began expanding rapidly from 1984 as production in Qiaotou soared to include over 4,000 stalls, 28,000 varieties of buttons, 14,000 employees, and sales of over RMB2.6 billion (around $310 million) by 1995 (Kong, 2008). Operations in this period were still largely driven by markets. Qiaotou also began to enjoy a significant demand advantage as China's share of the global clothing export market began to rise sharply following the termination of the Multi-Fibre Arrangement in 2004 (Rasiah, 2012). China's share of world clothing exports rose from 4.0 per cent in 1980 to 8.9 per cent in 1990 and further to 18.3 per cent in 2000 and 36.9 per cent in 2010 (WTO, 2011, table 11.69). The economies of scale this created would provide a large stimulus to local button production.

However, the limits of market-based coordination of the growing industry became obvious from the late 1990s, at which time local firms in Qiaotou were unable to upgrade technologically. Government support and social networks helped provide the spur for technological upgrading from 2000 onwards. However, the button manufacturers remained mainly confined to activities with moderate technological capability requirements as design and R&D support evolved in design centres, R&D laboratories and universities that supplied these inputs through strong social networks established by the Yonjia county authorities. Annex 2 shows the stages in the activities of button manufacturers in China. The world class quality of button designs and materials saw leading buyers of garment value chains visiting Qiaotou exhibitions to seek new button designs to import. Over 160 international brands had started to source their buttons from Qiaotou by 2005. In fact, the entire cluster of activities – from button materials and design to complementary activities related to machinery and components, resins and dyes and other inputs – had developed in Qiaotou by 2006.

A long history of entrepreneurial experience of people who resided in Zhejiang province helped the progression of the firms, but effective coordination between Government, the entrepreneurs and markets was instrumental in the transformation of such an activity from a specialization in only manufacturing to cover the entire cluster, as well as, provide the firms with testing, training, materials, and design and R&D support. The local government of Yongjia took measures to govern and upgrade the infrastructure in the county by focusing on the development of an information channel that included industrial conferences to connect the button firms to the whole country, special industrial zones in the county and incubation facilities for new firms. They also mapped out and then filled in the missing components of the button cluster so as to generate a complete button ecosystem and support new brand development and its diffusion throughout the country.

[30] Some microenterprises employing just five people also existed, but these firms were not the main producers.

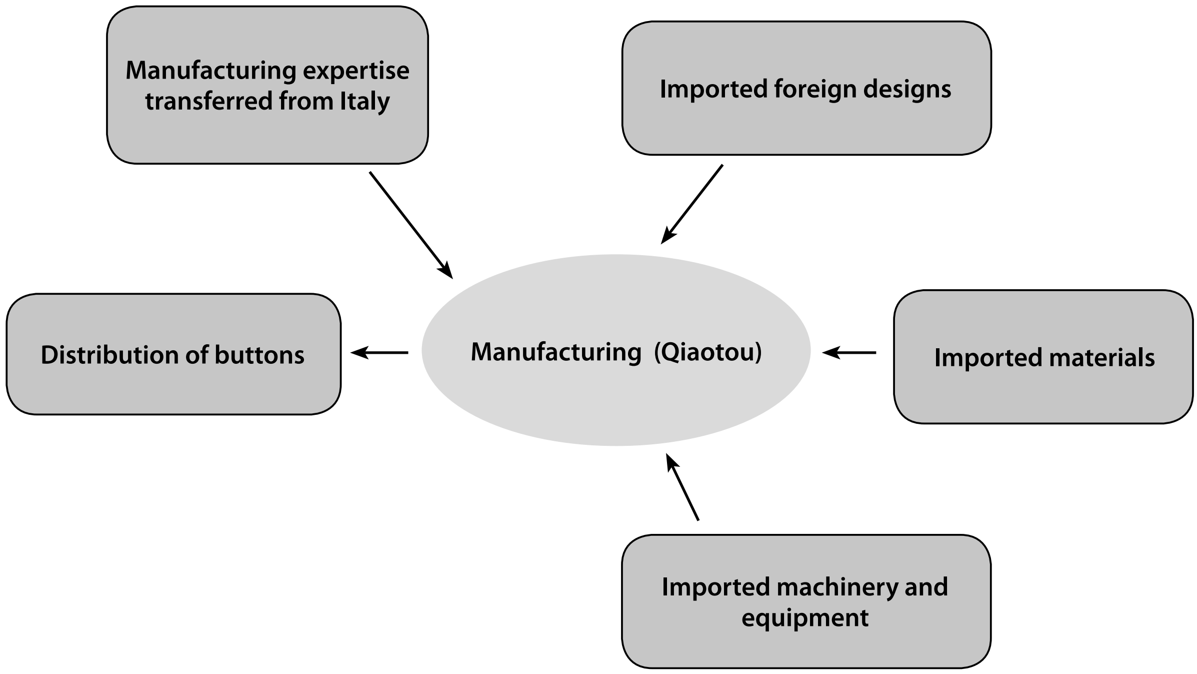
A button and slide fastener industrial park was built in Qiaotou to locate the firms with basic infrastructure connected with excellent roads, water and electricity supply, telecommunications, pollution disposal centres and Internet cables. The local government also offered lower land prices and regulation fees for industrial operations with standard factory buildings. To assist firms to resolve collective action problems in fields such as training, testing and technological upgrading, it either attracted or collaborated with meso organizations such as universities to support training, standards testing, design and R&D. Also, to support technological upgrading, the local government encouraged firms and universities to collaborate through science and technology projects. In 2006, the local government encouraged the private firms of Wenzhou Mailida and Dongda Integrated Chemicals to work with Huanan University of Technology to develop new technologies on raising button quality and recycling button material waste productively. New button technologies that were developed from such collaboration – both in product and environment-friendly and efficient production processes – helped raise value added of the industry by 2008 (Kong, 2008). While much of the technology has remained in Huanan University of Technology, the prototypes and new processes were diffused to the button manufacturers in Qiaotou.

The local government of Yongjia also established the pump and valve industrial science and technology innovation centre with collaboration from Lanzhou Technical University located in Gansu province in northwestern China, which provides technology information and human resource support for button manufacturing firms in Qiaotou. Especially the materials and machinery firms supplying equipment to button manufacturers benefited considerably from this centre, as the mineral-rich Gansu province produces polyester from petroleum waste and the chemical catalysts that are vital to button manufacturing. Indeed, polyester is the main material used to make buttons. The best button-making blanking and spinning machinery, however, is still imported from Germany and Italy. Indeed firms such as Yongjia Leiyu, Zhejiang Zida Dress, Jinfuda Garment Accessories and Decorations, and Yongjia County Hong Yu Clothing still use considerable machinery imports.

As a technology user, button-manufacturing firms benefited from the co-evolution of technology in materials, machinery and design from meso organizations started by the Yongjia government, including R&D support from technical universities, which was then translated into production in the button firms located in Qiaotou. While markets drove the initiation of the industry in Qiaotou, the Yongjia local government, in collaboration with the firms and meso organizations, played a critical role in the development of training, testing, design and R&D in both product and production technology, which was instrumental in stimulating technological upgrading in the industry. National organizations eventually became the key drivers of the upgrading process to support testing, training, design and R&D activities. Some critical meso organizations, such as Huanan University of Technology and Lanzhou Technical University centres, are located outside the province of Zhejiang and are not physically located within the Qiaotou cluster. The creation of external economies through these interventions and the production on a large scale by the industry were critical in enabling the success of the cluster (Krugman, 2009).

As sales of buttons to clothing manufacturers in China grew, there emerged strong interest to undertake the labour-intensive stages of button manufacturing in Qiaotou following growing concern over rising costs in Italy. Button manufacturing is also natural resource intensive, as polyester produced from petroleum waste is its main raw material (annex 2). Since the early 1980s, button producers in Italy were increasingly resigned to the relocation of this resource-intensive segment of button production, owing to increased competition. A significant amount of button manufacturing was gradually outsourced to firms in Qiaotou during the 1980s. The Italians supplied the nascent Qiaotou manufacturers with the designs and the machinery to produce them. They also helped link the suppliers of the raw materials from abroad to the Qiaotou manufacturers.

Figure 4 Button manufacturing in Qiaotou, 1985



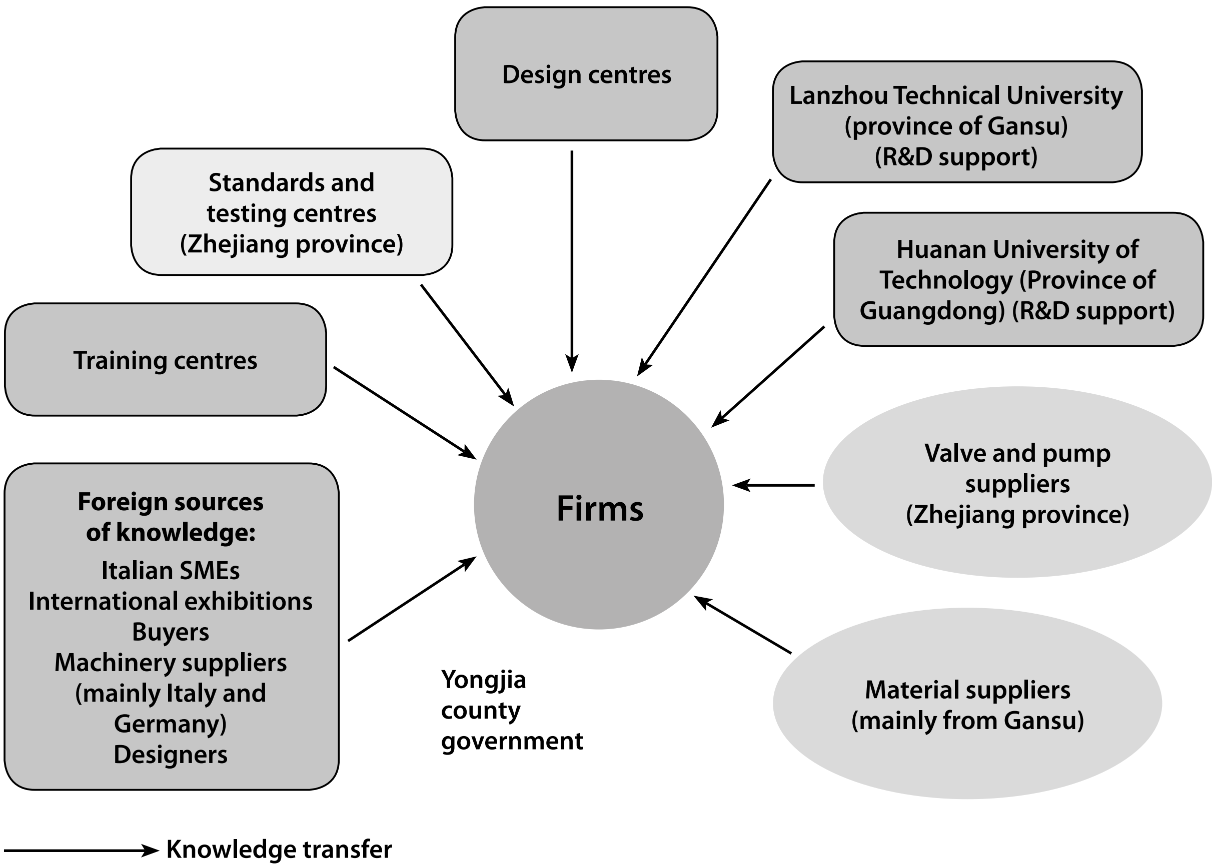
Source: the author.

Manufacturers from Qiaotou frequently attended exhibitions in Italy to pick out the best designs and buyers. The materials, machinery and equipment, and designs were imported from abroad as manufacturers in Qiaotou focused only on the low value added stage of the value chain (figure 4). Workers from China received their training to produce buttons in Italy, and officials from Italy also introduced inventory and quality control methods. This stage of production was also highly polluting.

Officials from Yongjia county decided in the 1990s to raise the quality of work of button (and zipper) firms in Qiaotou, and to attract to China the higher value added segments of the button (and zipper) value chains. Hence, Yongjia county officials met with the leading button producers in Qiaotou and officials from technical universities in order to develop the meso organizations essential to generate the knowledge and technology needed and transfer them to the button firms. However, unlike the HSIP experience where maturing firms were directly involved in R&D activities, the knowledge-intensive activities of button manufacturing evolved mainly in the meso organizations. Button manufacturers in Qiaotou have continued to specialize on the low value added stage of manufacturing. As shown in figure 5, button firms sought different types of knowledge and designs, materials and machinery from other organizations and firms.

Because of the nature of specialization and differentiation that evolved, the prototype designs have remained in the designing centres, while the material mixes (with polyester remaining the main material) and instructions have continued to flow out from the technical universities and design centres to the button firms. Huanan University of Technology (Guangdong) and Lanzhou Technical University (Gansu) are the two major providers of R&D and new technologies to the button firms in Qiaotou. International button and other clothing accessory exhibitions have increasingly moved to Zhejiang province since 2007 to select state-of-the-art buttons carrying the latest material mixes and designs. Although

Figure 5 Technology transfer to button firms in Qiaotou, 2007



Source: the author.

foreign designers and buyers still ordered some consignment of buttons using international designs, the successful expansion of design centres in Guangdong and Zhejiang has led increasingly to the selection of Chinese designs.

Technological upgrading helped Qiaotou expand sales to an estimated 16 billion buttons in 2008.[31] Officials from Yongjia county also noted that Qiaotou produced an incredible 65 per cent of the world's buttons that year. The participation of Zhejiang province, where Qiaotou is located, in the development of new button designs with support from technical universities from the provinces of Guangdong and Gansu is so important that over 160 major fashion firms have visited button exhibitions in the province every year since 2005. Hence, despite the low-technology classification of buttons, Qiaotou has evolved to the frontier of the technology ladder of button manufacturing. The case illustrates how this was achieved through a mix of international technology transfer from abroad and national technology transfer through local meso organizations and firms along with national universities located outside the cluster.

C. Technology transfer and industrial upgrading in the two clusters

This section has investigated the experiences of HSIP and Qiaotou in their efforts to reach the technology frontier in integrated circuit and button manufacturing. The cases contrast

[31] Estimate given by a Yongjia official on 29 December 2008.

experiences with different industrial specificities (covering high-, medium- and low-technology production), embedding structures and timing of the development of the respective industries. The former (integrated circuits) is a key component of high-technology products, while the latter is an accessory of low-technology clothing manufacturers. These initial conditions and the nature of interventions by local and national governments with strong coordination between the emerging firms and foreign sources of knowledge helped stimulate technology transfer and technological catch-up in the firms.

Both integrated circuits and buttons were new to the two locations of HSIP and Qiaotou at the time of initiation. The extent of government support varied with the public knowledge involved and the capital intensity of the industry.[32] R&D, integrated circuit design and wafer fabrication are highly knowledge intensive and hence expenditure by the Taiwanese authorities was extensive and on a national scale. In addition, wafer fabrication is also highly capital intensive. Button manufacturing uses critical technology from other industries so much so that the R&D involved in improving the production process is less sophisticated than in the development of new and better materials and metals, machinery and equipment, and designs. In line with Nelson (2008), the structure of the host and the timing of initial entry and subsequent focus on upgrading also matters in the nature of evolution of industry. The small-size framework of button entrepreneurs who connected with the button value chain from Qiaotou and the general structure of entrepreneurial activity in Taiwan Province of China meant that firm structure would not be heavily skewed towards integrated value chains activities. Hence, although UMC and TSMC are large and now spread across a number of countries, they specialize in wafer fabrication. The integrated circuit design firms have remained small and human capital intensive. Assembly and test activities are the most labour intensive, but these stages have also increasingly become knowledge intensive, with the leading firms enjoying supportive R&D activities. Whereas some design firms specialize exclusively in integrated circuit design, most of them specialize on the basis of scope to support other technological activities. Except for a few large firms, button manufacturers in Qiaotou specialized only in the production of buttons with engineering support to improve process technology and adaptations.

Through different paths and formations of institutional framework defined by the specificity of industry, locational structures and timing of entry, the integrated circuit cluster of HSIP and button cluster of Qiaotou moved to the technology frontier in their respective industries. Integrated circuits are the most important component in computers, hand phones, intelligent navigation systems and many other electronic devices. Button manufacturing in Qiaotou evolved from simply supplying imported buttons to clothing manufacturers in China to its actual production and sale to domestic clothing manufacturers and exports. Both locations relied extensively on foreign sources of knowledge initially before gradually transforming to greater reliance on domestic sources of knowledge. The expansion of domestic organizations initially intensified technology transfer from foreign to domestic organizations and firms, but the focus gradually shifted to stimulating knowledge development in domestic sources in both experiences.

Institutions, shaped through a blend of markets, cultural bonds and government regulations, incentives and grants, helped evolve the meso organizations of ERSO and later the HSIP. During the different phases of technological transformation from 1974 until the ending of public funding in 2000, they were critical in successful technology transfer and technological upgrading of integrated circuit production in Taiwan Province of China. The foreign sources of knowledge transferred to nascent Taiwanese firms included the acquisition of foreign TNCs (e.g. RCA), mergers with foreign TNCs (Phillips), and licensing, and through the relocation and circulation of knowledge embodied in national human capital. Taiwanese firms also learned considerably from knowledge interactions with buyers and suppliers. The development of capabilities nationally – through ERSO, HSIP and the universities – were also important in

[32] A public good is defined as a good whose consumption by one agent does not preclude its consumption by others.

not only providing the absorptive capacity to quicken learning but also the capacity to upgrade and innovate. All production-based firms in HSIP investigated in this paper showed advanced technological mastery using best practices and enjoying process-designing capabilities. The specificity of the Taiwanese economic structure also led to the creation of a new business model in which Taiwanese firms began to specialize in the individual stages of the value chain. The expansion of the anchors of foundry fabrication houses and the enabling of knowledge faculties in universities, training centres, meso organizations and firms stimulated the expansion of design firms at HSIP. While government support was important in the origin of national integrated circuit firms, including the fabrication houses and R&D centres, private firms had taken over all the activities by the late 1990s. The role of the authorities has since been limited to the provision of grants to firms seeking to undertake R&D and to new firms seeking incubation support at HSIP.

From markets (factor price of labour and final button prices) as the initial driver of button distribution and subsequently the relocation of its manufacturing, the county government of Yongjia was instrumental in gathering a powerful public–private partnership in planning the introduction of meso organizations to provide designs, new material mixes, and machinery and moulds in Qiaotou. The Technical University of Lanzhou from the province of Gansu was able to adapt newly evolving metal, carbon and plastics technologies to develop new button compositions. Huanan University of Technology from Guangdong province assisted by generating new button designs. Most button producers have already upgraded their technological capabilities to the point where they have mastered best practices and achieved adaptive innovation capabilities. Because of the nature of the technology, which is classified as low technology, design and R&D activities were largely confined to the laboratories outside the firms. The Qiaotou experience obviously shows that large labour reserves and a large domestic market are useful in attracting market-driven production, but technological upgrading required the infusion of government support through capitalization for R&D. Although the Yongjia county government was instrumental in the initiation of design centres in China, the capacity of private firms to assume such roles completely is evident from the two firms that have increasingly developed such capabilities from 2008. However, government support is still considered important in leading R&D activities at the technical universities.

Whereas the initial integrated circuit firms were completely incubated from ERSO before they ended up being led by Taiwanese experts with tacit and experiential knowledge, private entrepreneurs owned and managed button firms in Qiaotou. Incubators were helpful in developing machinery, pump and valve firms, which are used in the production of buttons in Qiaotou. The co-evolution of technologies from HSIP's high-technology infrastructure helped provide the base for rapid launches of new products. Government support was important in both cases.

The lessons from the two technologically diverse industries are important for other developing economies. First, industries completely new to a location can be promoted if the investment, technology and human capital needed for production can be provided, and market demand is present.

Market demand can be domestic and/or external. Where countries are large (such as China) domestic demand can provide a large market. However, small economies (such as Taiwan Province of China) must export in order to appropriate scale economies. An accessory such as buttons enjoys scale advantages when the domestic market is very large. With a huge domestic market, and as the largest exporter of clothing in the world, China obviously has the scale to support Qiaotou's progress in manufacturing buttons.

Human capital may need to be created. Where knowledge-intensive industries such as integrated circuits are involved, countries may need to develop their own human capital, as well as take advantage of human capital already developed to initiate the early building blocks of high-technology industries. In Taiwan Province of China, the authorities launched efforts to promote high-technology production by establishing ITRI in 1973, following which it systematically supported the development of integrated circuit, computer and telecommunications technology. Taiwan Province of China in general, and HSIP in particular, benefited from expert advice from TAC, which became an important provider of strategic intelligence, identifying strategic industries for promotion.

Regarding investment, the integrated circuit industry experience suggests that functional upgrading into wafer fabrication will require capital grants at least in the formative years. The Taiwanese authorities incubated the wafer fabrication plants by fully financing the acquisition of RCA and subsequently, the launching of TSMC as a joint venture with Dutch-owned Phillips, and spinning off the wholly national Yi-Wei, Taiwan Mask, and Vanguard. The less capital but highly knowledge-intensive stages of R&D and integrated circuit design also benefited from public funding in the formative years. All the early big integrated circuit firms also benefited from embodied technology through experiential knowledge gained through the diaspora working in leading integrated circuit firms in the United States. Latecomer countries in the integrated circuit industry such as Malaysia, Thailand, the Philippines, Indonesia and Viet Nam might follow a similar path if their Governments are keen on stimulating technological upgrading in the integrated circuit industry. It must be noted, however, that the integrated circuit industry has evolved profoundly and is more competitive today.

An additional element is the availability of natural resources for natural-resource-based production. In the case of buttons, the availability of large supplies of oil waste provided the main ingredient for button production.

The case of the button industry has significant implications for a wide range of low-technology industries. Industries such as leather goods, apparel and furniture can benefit from a specialization of R&D and design in R&D laboratories and technical universities provided that the country entering into production enjoys the appropriate natural resource and labour surplus endowments. Where technologies involve collective action problems such as leather treatment plants, and where R&D laboratories and government can bear the starting costs, then firms appropriating benefits from such support activities can gradually begin paying these costs. Design services – targeted at supporting low technology industries – could also be encouraged in the applied science and technical universities in these countries.

Annex 1. Measuring firm-level technological capabilities in HSIP and in Qiaotou, China

Table A1.1 shows a typology of taxonomies and trajectories of different levels of knowledge accumulation at the firm level, based on Rasiah (2010). The purpose of the table is to identify the taxonomic and trajectory features of technology upgrading so that technology transfer in particular settings can be better understood. In the formative years, incentives are often useful only in moving firms from level 1 to levels 2 and 3. Training and human capital supply organizations become important from level 2 onwards, increasing in importance as clusters mature technologically. Grants become more important to attract firms participation in the activities of levels 4 and 5. R&D scientists and engineers, R&D laboratories, and incubators become important at activities of levels 4 and 5.

In light of the sensitivity of technological depth to industrial specificity, the formulation of the different stages of technology is undertaken inductively to take account of the special characteristic features of the industries examined in this report. The following firm-level typology by taxonomy and trajectory is framed to examine technological upgrading in integrated circuits and button firms following brainstorming sessions with the industry associations in HSIP, Taiwan Province of China (integrated circuits) and Yongjia county, China (buttons) (see table A1.2). Technology transfer is important in all phases and with the three categorizations of technology used with the transfer of the higher levels of technology being easier and useful as firms reach level 6. Although the two industries are different, an attempt is made to classify equivalent stages together.

Table A1.1 Institutional pillars for technological upgrading of firms

	Basic infrastructure	*High-technology infrastructure*	*Network cohesion*	*International markets*
Initial phase (1)	Political stability and efficient basic infrastructure	Critical mass of economic agents	Social bonds driven by the spirit to compete and achieve	Connecting to the international economy
Learning phase (2)	Strengthening of basic infrastructure with better customs and bureaucratic coordination	Import, learning by doing and duplicative imitation, human capital development	Expansion of tacitly occurring social institutions to formal intermediary organizations to stimulate connections and coordination between economic agents, and meso organizations	Access to foreign knowledge through machinery and equipment import and FDI; integration in global value chains
Catch-up phase (3)	Basic infrastructure capable of providing essential services	Import, creative duplication and innovation; beginnings of Mark I system of learning	Smooth links between institutions and micro agents with meso organizations connecting and coordinating to solve collective action problems	Access to foreign knowledge through licensing, acquisition and imitation, through imports and exports; upgrading in global value chains, intellectual property rights regulation starts here
Advanced phase (4)	Advanced basic infrastructure instruments	Developmental research to support creative destruction (Schumpeterian Mark 1).	Participation of intermediary and government organizations in coordinating technology inflows, initiation of commercially viable R&D; strong macro, meso and micro coordination	Access to R&D human capital and collaboration with R&D institutions, high-technology resources and markets abroad
Frontier phase (5)	Novel basic infrastructure supports new developments in basic infrastructure	Basic research to generate new knowledge (Schumpeterian Mark II system)	Participation of macro, meso and micro agents in two-way flow of knowledge between them	Connecting horizontally with frontier nodes of knowledge

Source: Rasiah (2010).

Table A1.2 Taxonomy and trajectory of firms

Knowledge depth	*Human resources*	*Process*	*Product*
Simple activities (1)	On-the-job and in-house training	Dated machinery with simple inventory control techniques	Assembly or processing of products, or component, CKD and CBU using foreign technology
Minor improvements (2)	In-house training and performance rewards	Advanced machinery, layouts and problem solving	Original equipment manufacturing capability; firms have their own technology to make products
Major improvements (3)	Extensive focus on training and retraining; staff with training responsibility	Cutting-edge inventory control techniques, SPC, TQM, TPM	Cutting-edge quality-control systems (QCC and TQC) with minor changes to product
Engineering (4)	Hiring engineers for adaptation activities; separate training department	Process adaptation: layouts, equipment and techniques	Product adaptation
Early R&D (5)	Hiring engineers for product development activities; separate specialized training activities	Process development: layouts, machinery and equipment, materials and processes	Product development capability; some firms take on original design manufacturing (ODM) capability
Mature R&D (6)	Hiring specialized R&D scientists and engineers wholly engaged in new product research	Process R&D to devise new layouts, machinery and equipment prototypes, materials and processes	New product development capability, with some taking on original brand manufacturing capability

Source: Developed from Lall (1992) and Rasiah (1994, 2007).

Firm-level technological capabilities in HSIP, Taiwan Province of China

The technological capabilities of 18 integrated circuit firms located in HSIP are presented in table A1.3 to examine their closeness to the technology frontier. The fieldwork on these firms was undertaken by the author in September 2009 at the HSIP. Because the HSIP has reached level 5 development of the institutional pillars shown in table A1.1, the technological capabilities of Taiwanese firms can be expected to be at levels 5 and 6 (table A1.2). The specialization of Taiwanese firms on particular stages of production means that some firms may not be at level 6, though, all firms in the sample undertake R&D activities to support their own functions. For example, assembly and test firms such as ASE, which has a plant in Kaoshiung in south-western Taiwan Province of China, carries out process R&D to support its activities. TSMC and UMC carried out R&D on chip implant, though they undertook little chip design and held no brand names. By ownership, 15 were national and 3 were at least majority-share foreign owned. By specialization, 4 national firms only undertook designing activities and 6 carried out wafer fabrication. While all four of the national fabrication plants carried out R&D operations only two of them also undertook designing activities. Five firms were engaged in assembly and test activities but had engineering and designing capability to support rapid changes in production. The assembly and test firms also had subsidiaries in Malaysia, the Philippines and China. All three foreign firms in the sample were engaged in assembly and test operations with engineering and design capabilities. Strategic technology alliances with buyers were the prime market channel for all the Taiwanese integrated circuit firms in the sample. TSMC accounted for slightly over 50 percent of the world's sales revenue of fabricated wafers among foundry houses in 2010. None of the foreign firms were engaged in frontier R&D or marketing operations in Taiwan Province of China.

Table A1.3 Technological depth of integrated circuit firms at HSIP, 2008

	Human resource		*Process*		*Product*	
	National	*Foreign*	*National*	*Foreign*	*National*	*Foreign*
1	9 (60)	3 (100)	9 (60)	3 (100)	9 (60)	3 (100)
2	9 (60)	3 (100)	9 (60)	3 (100)	9 (60)	3 (100)
3	9 (60)	3 (100)	9 (60)	3 (100)	9 (60)	3 (100)
4	9 (60)	3 (100)	9 (60)	3 (100)	9 (60)	3 (100)
5	15 (100)	3 (100)	15 (100)	3 (100)	15 (100)	3 (100)
6	6 (40)	0 (0)	6 (40)	0 (0)	6 (40)	0 (0)

Source: The author.
Note: Figures in parentheses refer to percentages.

Firm-level technological capabilities in Qiaotou, China

Button manufacturers have since the 1990s begun to take the introduction of best practices in manufacturing seriously. Using a sample of firms drawn randomly from earlier research undertaken in 2007 (Rasiah, Kong and Vinanchiarachi, 2011) and on the basis of technological capabilities, it can be seen that no firm was engaged in level 6 knowledge-based activity in 2008 (table A1.4). Three per cent of firms were engaged in level 5 knowledge-based activities in HR and process technology, and 2 per cent of them, in product R&D activities. Interviews showed that some 19 firms enjoyed strong collaboration that involved its employees regularly working on the prototypes with the scientists and designers in the meso organizations located in Lanzhou Technical University and Huanan University of Technology.

The 100 surveyed button firms in Qiaotou are reported to have at least level 2 knowledge-depth activities in 2008 (table A1.4). Between 72–75 per cent of the button firms reported having in place cutting-edge best practices such as ISO 9000 series certification and materials requirement planning. At the time of writing, officials mentioned that efforts were being made by the Yongjia county officials to promote the introduction of the ISO 14000 series to reduce the production of polluting effluents by the button firms. Indeed, collaboration between Lanzhou University and standards organizations in Zhejiang was reported to be targeted at problem-solving layouts.[33] The new technology is then expected to be transferred to the button firms. Between 33–39 percent of the button firms in the sample reported hiring engineers and technicians who were actively engaged in the adaptation of machinery, layout and product adaptations, and in the strict implementation of best practice standards – such as ISO 9000 series and ISO 14000 series on environmental standards. Two firms (Wenzhou Mailida and Dongda Integrated Chemicals) worked jointly with the meso organizations in the designing and development of new material, design and equipment technologies.

Table A1.4 Knowledge depth of button firms in Qiaotou, 2008

KD	*HR*	*PT*	*RD*
1	100 (100)	100 (100)	100 (100)
2	100 (100)	100 (100)	100 (100)
3	75 (75)	75 (75)	72 (72)
4	39 (39)	37 (37)	33 (33)
5	3 (3)	3 (3)	2 (2)
6	0 (0)	0 (0)	0 (0)

Source: Compiled from Kong (2008).
Note: There were no foreign button firms in Qiaotou in 2008.

33 Work teams focused on reorganizing the physical layout of process flows and worker locations, as well as adapting machinery to reduce injury and expedite task performance.

Annex 2. Production stages for integrated circuit and button manufacturing

Integrated circuit production stages

1. The implanting specifications are undertaken through R&D in this stage. The miniaturization process in the production of integrated circuits is carried out here. Typically this is done in state-of-the-art wafer fabrication plants. However, some fabless lead integrated circuit firms also carry out such R&D activities.
2. Designing firms undertake chip design to define their functions. The chips are then manufactured by the fabrication plants. For every unit investment this is the most knowledge-intensive stage of integrated circuit production.
3. Fabrication of wafers involves etching, masking and photolithography, whereby the actual circuits are implanted in silicon wafers. This is the most capital-intensive stage of integrated circuit production.
4. Dies are sawn, detached from the wafers and subsequently attached and assembled onto frames before being moulded or packaged and laser marked. Most stress and durable tests are also carried out in this stage.
5. Functional tests are performed in this stage.

Source: Adapted from Marsh (1981).

Button production stages

1. Raw materials, primarily polyester drawn from petroleum waste, is mixed with a chemical catalyst and wax.
2. The mixture is poured into a large rotating metal cylinder made of steel lined with chrome. The cylinders are normally set on rollers that rotate the drums. The centrifugal force generated helps spread the mixture around the drum to form an even sheet. The thickness of the sheet is determined by the thickness of the buttons to be produced.
3. The chemical catalyst helps to harden the mixture as the cylinder rotates. The liquid hardens with the wax moving to the surface of the sheet.
4. Once the sheet hardens, the cylinder is stopped and the sheet is cut, which is then rolled out onto a wooden tube. The wax is then peeled off.
5. The sheet is then moved into a blanking machine on a conveyor belt. Circular steel dies cut button-sized blanks out of the sheet as the blanking machine passes through the conveyor belt.
6. The blanks are then collected in a nylon bag, which is then lowered into a tank containing salt water. The salt water is then heated up to over 100 degrees Celsius before being moved into a cold water tank where it is slowly cooled down.
7. The buttons are cut and shaped along the design specifications ordered by clothing manufacturers using a steel tool.
8. The final stage consists of a finishing process in hexagonal tumbling drums. Using water, an abrasive material and a foaming agent, the drums containing the buttons are spun to smoothen and shine them.

1 Raw material	2 Rotating metal cylinder	3 Hardening	4 Sheet cutting	5 Button cutting	6 Cooling	7 Styling	8 Finishing

Source: Prepared by author based on interviews with button firms in Qiaotou, 2008.

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Chapter 3. Technology transfer and the development of the automobile industry in South Africa

Introduction

The automobile industry has a long history in South Africa. The first plants were established in the 1920s by Ford and General Motors. Other firms followed, frequently with some local ownership, but always with technology supplied by the transnational vehicle producer. There then followed a long period of protective measures, and increasingly stringent local content regulations were introduced from the early 1960s. Export-promotion policies and partial liberalization followed in the 1990s.

The industry is currently extensively integrated into global production networks with high levels of foreign ownership. It produces high-quality vehicles and components for domestic and export markets. This level of development has naturally required large scale transfers of technology, and the industry has developed a reasonably high level of technological capability, especially with regard to process development. However, the sector remains highly dependent on imported technology, levels of domestic R&D are low and there are limited links to the local science and technology establishment. In this sense the sector differs considerably from other sectors of South African manufacturing, where domestic firms play a bigger role and there are higher levels of domestic R&D.

This section analyses the transfer of technology into the sector drawing on available literature and data, as well as large numbers of interviews carried out by the author over the past two decades. Section two provides an overview of the impact of protection and globalization on the mode technological upgrading and technology transfer in the automobile industry. The development of the South African industry and the impact of policy support is outlined in section three. Technological developments in the stages of protection and liberalization are analysed in section four. An assessment of the main modes of technology transfer is provided in section five. Section six concludes with policy recommendations.

3. 1. Protection, globalization and technical change in the automobile industry

In the automobile industry and in other sectors where sector specific policies play a key role, these tend to overshadow the impact of more generic policies aimed at promoting technological development. As demonstrated below, the policies first of protection and then of export promotion and limited liberalization have strongly influenced the structure of the industry which in turn has had major implications for the type of technology transfer.

In countries with limited markets and significant protection such as was historically the case in South Africa, plants were frequently small in relation to those in the developed world and had a diversified product mix. Production below optimal scale required simpler, lower capacity machinery (Black, 2011). This led to lower levels of automation and weakly developed layers of supplier firms, which resulted in higher levels of vertical integration within the firm than would be the case in developed countries (Katz, 1987). This reduced the level of technological specialization.

Work, especially in Latin America by Katz (1987) and others,[34] showed that many of the firms within protected industries may have been technologically dynamic within the parameters in which they operated, with rapid learning taking place and considerable accumulation of technological capability. However, as a result of the trade regime, industrial structure and factor prices under import-substituting industrialization, part of this effort was misdirected in terms of benchmarks of international competitiveness. An example is the vast amount of effort in areas such as logistics, materials flow, machine changeovers and production scheduling that is undertaken to deal with the problems of complexity that arise in low-volume, multi-product plants, which have frequently characterized the automotive and components industry in developing countries (Black, 2011).

[34] See Herbert-Copley (1990) for a review of this literature.

The problem, therefore, was not so much a lack of technological effort but that cost minimization and achieving optimal potential from world-scale plants was not the central objective of technological effort. These observations will be shown to have a clear resonance in the pre-liberalization phase of the South African automotive sector.

Greater openness usually leads to an expansion of international linkages, including greater FDI. Whether they establish greenfield sites or take over existing enterprises, foreign firms bring with them new technology and may establish new supplier networks involving both domestic and foreign firms. Two issues are of direct concern here. The first is the role that foreign links may play in enabling existing local firms to upgrade their technology and successfully integrate themselves into global networks. The second is the related question of the impact of increasing internationalization and foreign ownership on the capabilities of the domestic industry.

The restructuring of production networks has important implications. In the automotive industry, the trend towards using fewer first-tier suppliers and the greater use of foreign owned suppliers has had a major effect in emerging markets. For domestically owned firms, much will depend on the terms under which they are able to position themselves in these developing regional and global production networks. They may emerge as favoured first-tier suppliers, or be relegated to a more subordinate position as second-tier suppliers or even find themselves excluded completely and increasingly dependent on supplying the market for replacement parts. In seeking to optimize their position, domestic suppliers may seek out a foreign partner who can provide the technology necessary to supply export markets and meet the increasingly demanding requirements of domestic vehicle assemblers.

The literature on the impact of FDI on the upgrading of domestic firms provides mixed evidence. For instance, the inflow of foreign capital may create a more demanding and competitive environment requiring domestic firms to upgrade but it may also limit the need for indigenous technological adaptation (Lorentzen and Barnes, 2004), which can lead to downgrading both in terms of technological activity and in the value chain. For example, the integration of vehicle production into global networks requires completely standardized specifications doing away with any requirement for local adaptations. But a higher level of absorptive capacity and more robust capabilities within domestic firms and the host economy generally, are likely to lead to more positive spillovers and more developed linkages with the domestic economy (Narula and Dunning, 2000; UNCTAD, 2001; Lall and Narula, 2004).

Humphrey and Salerno (2000) refer to the increasing centralization of design by automobile and component TNCs and the fact that in countries such as Brazil, first-tier suppliers are now virtually all foreign owned. Rasiah (2007) found that foreign automotive component firms in East and South-East Asia were less R&D intensive than their local counterparts. However, Humphrey and Salerno (2000) also point to the emergence of a "sun and planets" model in which developing countries have regional design centres linked to the global design headquarters. In some cases these regional centres can undertake relatively minor R&D linked for instance to minor modifications required to deal with particular climatic conditions. But they can also involve more fundamental research. An example is the significant eastward shift in automotive R&D that has taken place in Europe.

A key form of linkage with the domestic economy is through purchases of inputs. There is considerable international literature citing the limited linkages that foreign firms have with domestic firms or with the domestic economy more broadly.[35] But there is considerable evidence that where large-scale assembly plants are established by foreign firms, considerable backward linkages can develop. And the level of linkages is not static. In the Mexican automotive industry, substantial upgrading occurred although much of this was with other foreign-owned firms rather than with Mexican suppliers (Carrillo, 2004). For Poland, Domanski and Gwosdz (2009) report similar developments with significant upgrading by foreign affiliates of TNC component suppliers. In a study of Volvo truck and bus plants in developing countries, Ivarsson and Alvstam (2005) found that while follow-source suppliers had gained a large share of purchases by these assemblers, the technology transfers to domestic firms were very significant.

35 See for instance, Turok (1993) and Jenkins (2006).

The impact of liberalization and FDI on technology transfer and upgrading is therefore very much contingent on circumstances. What is clear is that the nature of learning and technical change changes substantially when the trade regime is liberalized and even more so if ownership changes. Larger firms, especially foreign firms, are frequently better placed to benefit from liberalization (Carillo, 2004; Black, 2009). For domestic firms, including those which come under foreign ownership, there is certainly potential for deskilling, but there are substantial opportunities as well.

While global production networks are well established in the automotive industry, a more recent development is the emergence of global innovation networks whereby some knowledge-intensive activities are based in developing countries (Lorentzen and Gastrow, 2012). Again the form that these take is specific to the particular sector. Power in the global automotive industry is highly concentrated with the bulk of frontier innovation taking place in a handful of TNC vehicle manufacturers and first-tier component suppliers in developed countries. Barriers to entry for firms from developing countries are therefore high (Lorentzen and Gastrow, 2012). But in very large dynamic markets such as China, India and Brazil, it can make sense to adapt existing models or produce emerging market models and locate regional design headquarters in these centres (see, for example, UNCTAD, 2005). In other regional centres, a large production presence and relatively low engineering costs may also lead major automobile firms to locate significant R&D in these sites. Examples include Thailand, which is a regional centre for Japanese automobile firms, and Poland, which hosts major R&D centres for TNC firms. Firms in developing countries may also acquire technology by purchasing developed country firms through outward FDI. High-profile examples have included the purchase by Tata of Jaguar and Land Rover and the acquisition of Volvo by the Chinese firm, Geely.

Table 4. South African production and exports of passenger cars and light commercial vehicles, 1995–2012

	Passenger cars				*Light commercial vehicles*			
	Market			*Exports as a % of total*	*Market*			*Exports as a % of total*
	Domestic	*Exports*	*Total*		*Domestic*	*Export*	*Total*	
1995	233 512	8 976	242 488	3.7	127 363	6 356	133 719	4.8
1996	231 616	3 743	235 359	1.6	128 516	7 125	135 641	5.3
1997	215 784	10 458	226 242	4.6	113 204	8 000	121 204	6.6
1998	174 870	18 342	193 212	9.5	98 056	6 806	104 862	6.5
1999	159 944	52 347	212 291	24.7	95 326	6 581	101 907	6.5
2000	172 373	58 204	230 577	25.2	104 121	9 148	113 269	8.1
2001	172 052	97 599	269 651	36.2	113 111	10 229	123 340	8.3
2002	163 474	113 025	276 499	40.9	101 956	11 699	113 655	10.3
2003	176 340	114 909	291 249	39.5	102 007	11 283	113 290	10.0
2004	200 264	100 699	300 963	33.5	123 467	9 360	132 827	7.0
2005	210 976	113 899	324 875	35.1	146 933	25 589	172 522	14.8
2006	215 311	119 171	334 482	35.6	159 469	60 149	219 618	27.4
2007	169 558	106 460	276 018	38.6	156 626	64 127	220 753	29.0
2008	125 454	195 670	321 124	60.9	118 641	87 314	205 955	42.4
2009	94 379	128 602	222 981	57.7	85 663	45 514	131 177	34.7
2010	113 740	181 654	295 394	61.5	96 823	56 950	153 773	37.0
2011	124 736	187 529	312 265	60.1	108 704	84 125	192 829	43.6
2012	121 677	153 196	274 873	55.7	112 118	123 623	235 741	52.4

Source: AIEC (2013).

3. 2. The South African automotive industry: An overview

The South African vehicle market grew very rapidly from 1950 to the early 1980s, with sales increasing tenfold over this period. The market stagnated during the 1980s as the economy entered a phase of very slow expansion with growth constrained by political instability and increasing international isolation. Solid growth followed the installation of democratic government in 1994, with sales reaching 714,000 vehicles in 2006 before the slump induced by the global financial crisis. Domestic sales in 2012 of 624,000 vehicles constitute a fairly small market in global terms, and the regional southern African market, apart from South Africa, is tiny (although growing rapidly). In 2012, 540,000 vehicles (all types – see tables 4 and 5) were produced, of which 278,000 were exported (AIEC, 2013). Vehicle production has tracked domestic sales closely, but rising imports have meant that it has failed to keep pace with the expansion in the domestic market.

Since vehicle assembly was established in South Africa by United States firms nearly 100 years ago, nearly all the major global automotive brands have had a production presence in the country, although in some cases this was minimal. Chrysler and Peugeot began production before World War II but this was later discontinued. Fiat began production in the 1960s but this later also ended. As political pressure mounted on apartheid South Africa in the 1980s, Ford and GM disinvested, selling out to local interests. Japanese firms were barred by the Japanese Government from making direct investments in South Africa, although there was extensive trade. Toyota and Nissan production plants in South Africa were therefore locally owned firms operating under licence. Democratization in 1994, combined with the pressures of globalization, changed the dynamics completely.

There was a rapid increase in foreign ownership, and all assemblers are now wholly owned by foreign TNCs. Currently there are several producers of light vehicles in South Africa (table 6) and there have been no major new entrants into the assembly industry over the last two decades. There has also been growing foreign ownership in the component sector, which

Table 5 Assembly of medium and heavy commercial vehicles and buses in South Africa, 1995–2013

	Market			*Exports as a % of total*
	Domestic	*Exports*	*Total*	
1995	12 753	432	13 185	3.3
2000	12 275	679	12 954	5.2
2005	27 406	424	27 830	1.5
2010	22 021	861	22 882	3.8
2011	26 656	803	27 459	2.9
2012	27 850	1 074	28 924	3.7
2013	29 700	1 300	31 000	4.2

Source: AIEC (2013).

Table 6 Light vehicle producers in South Africa, 2012

Passenger cars	*Model*	*Location of assembly plant*
BMW	3 Series	Rosslyn (near Pretoria)
Mercedes-Benz	C-Class	East London (Eastern Cape)
Nissan/Renault	Livina, Sandero	Rosslyn (near Pretoria)
Toyota	Corolla, Fortuner	Durban
Volkswagen	Polo	Uitenhage (Eastern Cape)
Light commercial vehicles		
Ford/Mazda	Ranger, BT-50	Pretoria
General Motors	Chev Utility, Isuzu KB	Port Elizabeth (Eastern Cape)
Nissan	Hardbody, NP300, NP200	Rosslyn (near Pretoria)
Toyota	Hilux	Durban

Source: AIEC (2013).

numbers some 350 firms. The majority of large firms (those with over 500 employees) are now foreign owned. The medium- and heavy-vehicle sector is small, albeit with a large number of producers such as Toyota, Nissan, Mercedes Benz, MAN, Scania and Tata. But these firms mainly operate semi-knocked down plants, which entail importing trucks in a virtually built-up form and only undertaking very minor assembly in South Africa.

The automotive industry is a major employer (annex 3, table A3.2), although employment in manufacturing has declined slightly since 1995, especially in the assembly industry. But overall, employment in the sector has performed better than other manufacturing subsectors. There has also been strong employment growth in the service sector (distribution, repair, fuel provision and so forth), which in any event is a far more significant source of employment.

The globalization of the South African industry has been driven by the introduction of the Motor Industry Development Programme (MIDP), which was introduced in 1995 and made provision for gradually declining tariffs and a system by which automotive exports earn import credits which allow them to offset import duties. It also provided for the abolition of local content requirements.[36] Prior to that, the industry had a long history of protection, which included high tariffs and a series of local content programmes. The first of a series of local content programmes was introduced in 1961 and followed by a series of adjustments which increased local content requirements (table 7). Considerable diversified development took place under this protective regime. Imports of vehicles were minimal. A major driver was FDI aimed at accessing the protected South African market, but there was also significant domestic ownership, especially in the component sector. The component industry developed significant investment and production capability as well as the capacity to innovate in process development and to a lesser extent in product development. A major problem was the failure to use some form of industrial policy to limit the excessive proliferation apparent in the large number of models and makes of vehicles being assembled in low volume. This in turn forced component firms to produce at far below minimum efficient scale.[37]

The problems of high protection and associated low volume production had become increasingly apparent by the late 1980s. South Africa's automotive industry was inefficient and highly inward oriented. Also, the international context was strongly supportive of trade liberalization and even apartheid South Africa was not immune to this trend. Phase VI of the local content programme, introduced in 1989, marked the beginning of reduced protection for the industry. The component sector was partly liberalized and vehicle producers could meet part of their local content requirements by exporting. However, tariffs on built-up vehicles remained at prohibitive levels.

The Motor Industry Development Programme (MIDP) was introduced in 1995, just a year after the first democratic elections. Tariffs, which exceeded 100 per cent until the early 1990s, were scheduled to phase down to 40 per cent for light vehicles and 30 per cent for components by 2002. Further tariff phase downs to 25 per cent by 2012 were scheduled at a later policy review.[38] Minimum local content requirements were also abolished with the introduction of the MIDP. Importantly, however, import duties on components and vehicles could be offset by import rebate credits derived from the export of vehicles and components. So while nominal duties on imported vehicles remained fairly high, the ability to rebate import duties by exporting enabled importers to ship in vehicles and components at lower effective rates of duty.

Another important change was that the medium- and heavy-vehicle industry was extensively liberalized with the rationale being that medium and heavy vehicles are capital goods and it was essential to make these available at the lowest prices possible. Duties on all major truck

36 For overviews, see Black (2001, 2009).

37 Minimum efficient scale varies according to the type of production process. Minimum efficient scale for vehicle assembly (approximately 100,000 units per model) is lower than for capital-intensive processes such as the machining and stamping of major components (Bureau of Industry Economics, 1988; Rhys, 2004). In 1995, the average volume per model for light vehicles assembled in South Africa was less than 10,000 units.

38 See annex 3, table A3.3 for the technical parameters of the MIDP.

Table 7 Phases of South Africa's automotive policy

Policy phase	Dates	Major policy measures
Phase I	1961–1963	Local content programme introduced to raise local content measured by mass from 15% to 40%
Phase II	1964–1969	Increase local content from 45% to 55%
Phase III	1971–1976	Set objective to raise local comment to 66% by 1977
Phase IV	1997–1998	Standstill phase – no change
Phase V	1980–1988	Applied local content requirement to light commercial vehicles
Phase VI	1989–1995	Calculation of local content based on value not mass Part of local content requirement could be achieved by exports
MIDP	1995–2012	Gradual phasing down of tariffs on vehicles to 25% by 2012 Abolition of local content requirement Import export complementation
APDP	2013–2020	No further tariff phase down Production incentive provides for rebate of import duties based on value added in production Automotive Investment Scheme provides grant for qualifying investments

Source: Black (1994); AIEC (2013).

components apart from tyres were reduced to zero. While tariffs on built-up trucks remained, the definition of "local assembly" in this sector meant that the cab could be imported in built-up form with only very minor local assembly required. The level of local content in these domestically assembled trucks is minimal.

In the scale-intensive automotive industry, exports were essential to achieve the higher volumes and greater specialization required to improve efficiencies. The ability to offset import duties would therefore provide the lever to encourage firms to export and thereby secure a more significant presence in global value chains. Essentially, what policy sought to encourage was a transition from completely knocked down (CKD) assembly, which has typically been characteristic of vehicle production in protected developing country markets, through a transition stage to full manufacturing[39] (table 8). This had profound implications for technological development. Under CKD assembly, production is usually at low volume and costs are high, especially if a high level of localization is stipulated by government policy. Local production capabilities may be developed together with limited product development capabilities to deal with adaptations of imported technology. In the transition and full manufacturing stages, where exports may become significant, both quality standards and the number of derivatives[40] offered need to be in line with international practice. Production volumes per model also increase in the transition stage and under full manufacturing would approach world scale. Local design may disappear as vehicle assemblers are fully integrated into the parent company global network and the emphasis will be on the transfer of modern technology and the upgrading of process technology and of the supplier network. But domestic design and adaptation is likely to disappear as these facets become fully integrated into global networks. On the other hand, as full manufacturing develops, subsidiaries in developing countries may take on R&D in specific areas. For example, Honda in Thailand is playing a small but growing role in the firm's global R&D strategy for small cars.[41]

39 Full manufacturing refers to modern, large-scale vehicle production in which all parts are supplied as separate subsystems and not in CKD packs.

40 Derivatives refer to minor variations such as number of doors and engine size. As assemblers became integrated into global networks they also had to offer greater variety in terms of features such as colour and trim.

41 Interview with Honda, Bangkok, 2013.

Table 8 Development stages of vehicle production in South Africa

	CKD assembly (Before 1995–2005)	Transition (1995–current)	Full manufacturing (2005–current)
Target market	Domestic	Domestic and export	Domestic and export
Level of integration with parent company	Low; import of CKD packs	Medium	High
Model line up	Many models	One or two	One or two
Derivatives	Limited to reduce costs	Full range to supply export market	Full range to supply export market
Local content	Generally low but may be high as a result of local content requirement	Moderate based primarily on cost factors	Medium to high
Quality	Below source plant	Equal to source plant	Equal to source plant
Production cost	High	Medium; penalties incurred by high logistics costs	Low
Domestic design	Local adaptations	None	None – may do worldwide R&D in niche areas

Source: Black (2009).

Note: The above schema is purely indicative. Dates given are approximate and vary from firm to firm, which explains why the stages overlap. In South Africa, Toyota and Volkswagen are the best examples of firms that have reached full manufacturing status, characterized by high-volume production for the local and international market and reasonably high levels of local content.

From 2013, a new programme, the Automotive Production and Development Programme (APDP) was introduced. An important reason for the introduction of the new programme was to remove the export subsidy element of the MIDP. In terms of the APDP there were no further reductions in tariffs, and incentives in the form of import credits are based on production rather than exports.

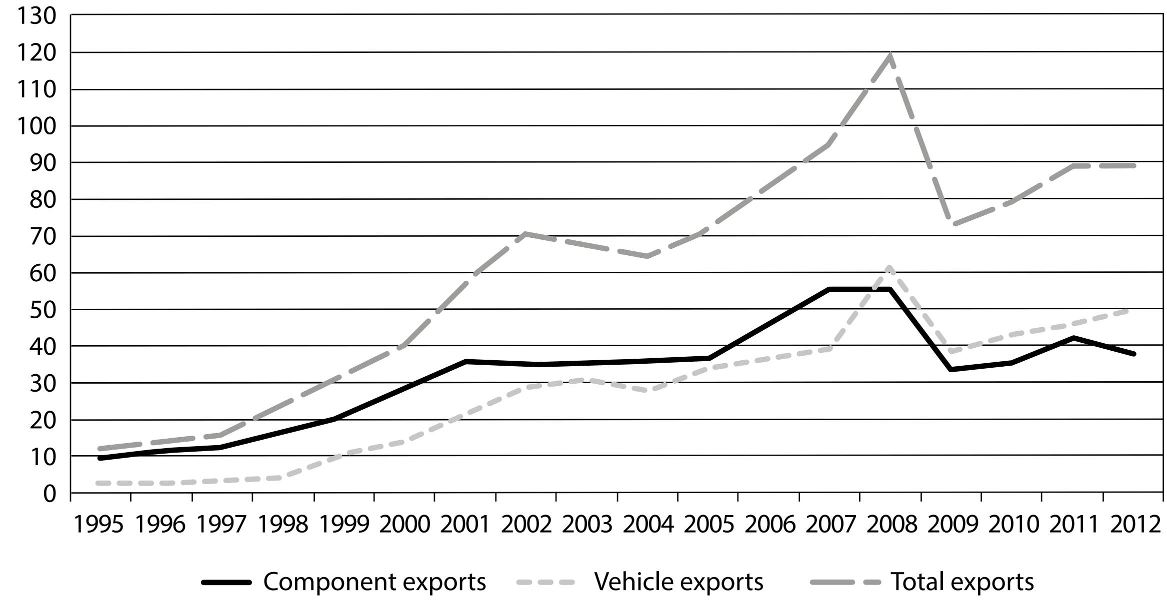
Impact of globalization on the structure of the industry

As a result of reduced protection, the level of international competition in the South African automotive industry has increased substantially, indicated most clearly by the rise in import share (Black and Bhanisi, 2007). International trade brings the prospect not only of export growth but of specialization, which is extremely important in a scale-intensive sector such as the automotive industry. However, as protection has been reduced, imports have gained a larger share of the domestic market and now account for over half of domestic sales. Total automotive imports (including vehicles and components) increased from R18.0 billion in 1996 to R73.3 billion in 2005 and R136.1 billion in 2012. Automotive products account for 16.3 per cent of total South African imports, a share which is virtually unchanged from 1995.

Exports have also grown rapidly (figure 6). Total automotive exports at the start of the Phase VI programme in 1989 were only R443 million but increased over one hundredfold to R45.6 billion by 2005 and R88.8 billion in 2012. A number of factors have accounted for this. The most important is the import–export complementation arrangements of the MIDP, which have powerfully assisted exports. A second factor has simply been that falling protection and limited domestic market growth have forced firms into the export market.

Because TNC vehicle producers controlled large global networks of assembly operations and linked supplier companies, they were able to rapidly facilitate exports either from their own South African operations or from South African-based suppliers to their international operations. Access to cutting-edge technology became important for suppliers. This frequently meant that it was essential for domestic firms to partner

Figure 6 South African automotive exports, 1995–2012 ***(R billion, constant 2012 prices)***



Source: NAAMSA Annual Reports (various years), *Automotive Export Manual* (various years), SARS.

with foreign firms in order to ease access to foreign markets. Firms were therefore encouraged to rapidly develop exports, and this meant a substantial reorientation of existing production and the necessity to re-position themselves in international value chains. For many, this was difficult. A number of divisions within the largest domestically owned groups such as Murray and Roberts, Metair and Dorbyl found themselves vacating the first tier of local suppliers for the second tier (Lorentzen and Barnes, 2004).

3. 3. Technological development in the South African automobile industry

The South African automotive industry has historically depended heavily on imported technology. In the early 1990s, as the first steps to liberalize the industry were put in place, firms were spending relatively little on R&D and were generally highly dependent on foreign licences. However, they were certainly not totally lacking in technological capacity (Black, 1994). On the product side, they possessed the capacity for design, even if only in a limited form. On the process side, firms were not only able to fully master the technologies they were working with but also to upgrade them by introducing adaptations. For instance, an aluminium wheel producer introduced modifications to the die cooling system, which reduced casting time to 180 seconds, compared with 300 seconds in Europe (Black, 1994). Some important innovations resulted from the experience of high-variety, low-volume production, which characterized the South African components industry. This technological capability is, however, of limited value in the international market place except in the production of certain low volume aftermarket and replacement parts.

A small survey of larger component firms conducted in the early 1990s, well before the introduction of the MIDP, found that firms were not lacking in technological capability.[42] Developing their own technology was difficult for most component firms, competing with TNC suppliers with huge R&D budgets. Firms were asked to rate their own technological capabilities

[42] See Black (1994). The survey included only 16 firms; therefore, the results should be seen as indicative. But they were supported by many less formal interviews.

Box 1. Alfred Teves Technologies (Ate): Low-volume production and the development of technological capabilities

Alfred Teves was established in the 1980s to produce braking systems under licence from Alfred Teves AG, which is now owned by Continental. In the late 1990s, Ate was confronted with very low volumes in the domestic market. It dealt with the problem in part by investing in flexible computer numerically controlled (CNC) equipment but also by expending large-scale technological efforts in incremental changes to increase flexibility. CNC equipment required a changeover time of only 20 minutes but was very slow with a machining time of 14 minutes per piece. Dedicated machining lines were designed for speed and comprised a set of eight hydraulically operated fixtures on a rotating table. Eight processes (drilling, milling and so forth) were, therefore, happening simultaneously. Machine changeovers on dedicated equipment are a complicated and arduous task involving removal of the machining table, fixture stations and tools and the disconnection of hydraulic clamping devices. These tasks were carried out by artisans. This type of dedicated machinery is not designed for frequent changeovers, and foreign technical experts visiting the plant had been amazed that what they considered to be machine rebuilds were carried out on a routine basis.

To reduce tooling costs for the wide diversity of part numbers produced, a number of innovations had been introduced. For example, broach tools had been divided into segments to make them more versatile. Another large investment was in milling cutters. The numbers of these required had been reduced by putting in special inserts which allow four sides of the cutter instead of two to be used. The pre-setting of tools on CNC equipment had reduced downtime in that area due to machine changeovers. On transfer lines, changeover times had been reduced from 16–20 hours to 6–8 hours.

Source: Black (2011).

on a scale ranging from very limited capacity (the ability to choose among alternative technologies) to the capacity to generate new products and processes. Most of the larger firms were able to adapt both product and process technology and a quarter of the sample (4 firms) claimed to be able to generate new products and processes. While for the most part these were minor adaptations, they were important in two ways. On the product side they illustrated the capacity for design, even if only in a limited form. On the process side, the findings showed that firms were not only able to fully master the technologies they were working with but also to upgrade them by introducing adaptations. A significant number of firms were also able to generate new products and processes. All these firms were locally owned (two were independent) and most devoted fairly significant resources to R&D. Most were specialized in terms of their product and were generally much more oriented to exports than the sample average.

A number of firms were also engaged in attempting to make machinery more flexible and new equipment was chosen with this in mind. Some important innovations resulted from the experience of high-variety, low-volume production, which characterized the South African components industry (Black, 1994). The case of brake manufacturer Alfred Teves Technologies (Ate) illustrates the cost penalties incurred by low-volume production and how this has influenced investment patterns and technological effort (box 1).

As one would expect in a scale-intensive sector with globally concentrated product development, the strengths of the local industry were primarily in process development. Exact product specifications were determined by vehicle assemblers, but processes had to be adapted to meet the low volume and wide product range of a small domestic market. Significant capabilities were developed over past decades in investment and production capability, process engineering, quality control and workforce skills. These capabilities were developed in a range of ways via the import of equipment, internal R&D and learning by doing. There are numerous instances where process innovations developed in South Africa have been transferred to a parent company or licensor. With the rapid increase in foreign ownership since 1994, direct transfers by foreign firms have increased.

In the era of heavy protection, certain adjustments were made to local vehicles to adapt them to local needs, and purely South African derivatives were also developed. Local adjustments included higher specification radiators and trim to deal with strong sunlight and higher temperatures, stronger suspension and superior dust-proofing.

A high level of standardization in the use of medium and heavy truck engines was achieved via very high protection for the State-owned engine producer, Atlantis Diesel Engines (ADE). ADE was established as a strategic company in 1981 as South Africa's political isolation deepened and economic sanctions became a real possibility. It manufactured diesel engines, castings and components using technology licensed from Mercedes Benz and Perkins. This in turn required considerable modification of a number of truck makes to take the Mercedes and Perkins engines produced by ADE.

The impact of protection on quality standards and supplier capability is a complex issue. On the one hand, the long period of protection enabled the domestic industry to acquire key manufacturing competencies in terms of production experience and quality. However, there is also no doubt that protection created distortions, which negatively impacted on efficiency. An extreme example was the deliberate building of heavier components during the period up to 1989 when local content was measured on a mass basis. The issue of complexity of specifications and standards poses a further problem for developing country industries. Staying at the world frontier in terms of new models and emission levels imposes considerable costs in terms of required investments in new tooling. However, falling behind makes it difficult to penetrate export markets, both for vehicles and components, although it may allow one to supply components to selected niche markets. South Africa continues to face difficult choices in this respect, as it is trying to increase exports to both highly developed countries and to the rest of Africa, where the demand is for rugged, less sophisticated vehicles.

Apart from minor product adaptation for the domestic market, there have been relatively few examples of local product development over the past two decades. Some firms producing less sophisticated products, mainly for the aftermarket, had proprietary technology and their own brand names. There were also a small number of firms producing more sophisticated products, which incorporated their own technology. The more notable cases involving advanced technology include alarms, anti-theft devices and aluminium wheels. Some of these resulted from the electronics expertise developed in the defence industry. A recent example was the development of a prototype electric car, the Joule, by Optimal Energy, a company launched by engineers with previous involvement in the defence industry. This project received significant start-up support from the State-owned Industrial Development Corporation (IDC) and the Department of Science and Technology, and the prototype received much acclaim. However, it could not secure the much larger funding required for commercial production, and the project shut down in 2012.

3. 4. Modes of technology transfer

Technology transfer takes place through a number of channels, such as foreign investment (either wholly owned or on a joint-venture basis), licensing, the purchase of imported capital equipment, the movement of skilled people or via collaborations with university and other research institutions.

Imports of machinery and equipment

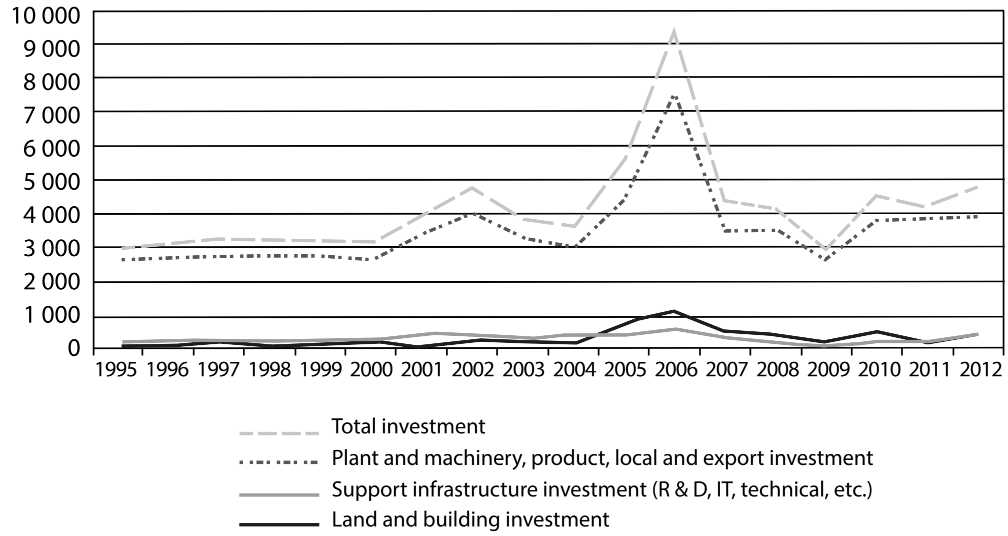
The major form of technology acquisition is through the purchase of machinery and equipment. According to the 2008 South African Innovation Survey (Department of Science and Technology, 2011), for all manufacturing enterprises, as much as 65 per cent of innovation activity was accounted for by the acquisition of machinery, equipment and software. This is also the case in the South African automotive industry. As indicated in table 9, technological transfer embodied in machinery is of great importance.

Table 9 Major channels of technology transfer for automotive component

Rank	Foreign firms	Domestic firms
1	Embodied in machinery (25%)	Embodied in machinery (25%)
2	Developed with a supplier (13%)	In house development (19%)
3	Hire of foreign personnel (13%)	Domestic licensing (17%)

Source: Derived from Kuriakose et al (2011), based on the World Bank 2003 Enterprise Survey.

Figure 7 Capital expenditure by South African vehicle manufacturers, 1995–2012 ***(R million, constant 2012 prices)***



Source: NAAMSA Annual Reports (various years).

The importance of the acquisition of technology via the purchase of machinery is confirmed by a survey of automotive component firms conducted by Buys (2010), who also found that foreign firms used more modern technology. Investment growth in the assembly industry has been moderate rather than spectacular, apart from the boom of 2005–2006 (figure 7). The same applies to investment levels in the component sector, where the factors driving investment are the rate of expansion of vehicle production, the levels of local content as well as direct exports.

Technology agreements and licensing

Technology agreements and licensing are probably more important in the automotive industry than in most other sectors. Although there was a high degree of local ownership until the late 1990s, the locally owned vehicle manufacturers and the bulk of locally owned, first-tier component producers operated using technology licensed from European, Japanese or United States firms. This involved royalty costs and also imposed restrictions on exporting, which was a serious constraint for some firms as the domestic market came under pressure and firms were forced to develop export strategies. In spite of these disadvantages, many firms considered licensing to be the most cost-effective way to obtain up-to-date technology. For example, although the State-owned diesel engine producer, Atlantis Diesel Engines, developed considerable process capability and was paying large amounts in technology licensing fees, at no stage did it consider trying to develop its own designs (Black, 2011). The lack of specialization in the industry also encouraged domestic firms to rely on licensed technology, as low volumes could not justify large investment in R&D. There has been a decline in the use of licensing as foreign ownership has increased but, in 2009, firms which licensed foreign technology were still spending as much as 2.2 per cent of sales revenue on royalties (Kuriakose et al., 2011: 69)

Role of transnational corporations

In the late 1980s, levels of foreign ownership were low, both among vehicle manufacturers and component producers in South Africa as a result of political and economic turmoil and the international campaign to encourage disinvestment from apartheid South Africa. This changed with the advent of democracy in 1994 and the country's reacceptance into the international community. The change in trade policy and resulting internationalization of the industry, manifested in growing exports and imports, had major implications for ownership. It became increasingly important for local firms to have links to global networks as a way of acquiring technology and facilitating access to international markets. In South Africa, and indeed in other emerging markets, foreign-owned assemblers increasingly prefer to source components from joint ventures and wholly owned subsidiaries rather than domestically owned firms.[43] The result for many South African component firms has been that they either needed to seek out an international partner or faced the prospect of being confined to the aftermarket (Barnes and Kaplinsky, 2000). The domestic firms that were able to achieve international success tended not to be first-tier suppliers and have included producers of automotive glass, electronic control units, aluminium wheels, exhaust systems, filters and burglar alarms.

Growing foreign ownership has accelerated technological upgrading but this has taken a particular form (Barnes and Morris, 2004). The main conduits have been through transfers from foreign sources rather than an increase in domestic R&D. Domestic firms, under pressure to upgrade their technological and production capacities, have turned to foreign sources of technology through the establishment of joint ventures, for example. The growing internationalization of the industry has also led to a number of informal transfers, and the number of foreign technical experts and advisers working in South African assembly plants and component firms has been increasing.

There has been some debate as to the impact of this. Earlier work by Barnes and Kaplinsky (2000) took a somewhat pessimistic view about the prospects for domestic suppliers, especially those without foreign connections. Lorentzen and Barnes (2004) and Lorentzen (2005) provide a generally more upbeat assessment of the prospects of domestically owned firms. In a series of case studies of South African component firms, Lorentzen (2005) argues that innovating firms tended to be either domestically owned or owned by passive foreign investors. The latter, by supporting the R&D strategies of local managers, may improve absorptive capacities in domestic subsidiaries, as opposed to typical TNCs, where decisions about upgrading or downgrading capabilities in a particular subsidiary will be subordinate to the overall demands of the worldwide group with possibly very negative implications. There is much evidence that when local component firms have come under the control of TNCs, existing R&D establishments are downsized or shut down.[44] It does not follow, however, that these firms downgrade technologically because the shutting down of formal R&D facilities can be accompanied by the introduction of new specialized product and process technologies which bring host firms closer to the world frontier. With global sourcing, locally owned firms may also stop carrying out adaptations and reduce their R&D capacity.

The import–export complementation policy has encouraged foreign owned vehicle producers to play a major role as conduits between domestic component firms and the international market as a method of earning more import credits. Assemblers have done this by arranging export contracts for component suppliers by facilitating access to their global networks. In the case of selected suppliers, this has led to new investment, the import of new technology and has accelerated the transfer of industry best practices in production organization.[45] But the main beneficiaries have been foreign-owned firms, and the components selected by vehicle producers have not necessarily contributed to strengthening the domestic supply base. For example, the major beneficiary of the expansion of component exports, arranged by vehicle producers to offset import duties, has been the catalytic converter industry. This subsector's exports increased from just R377 million in 1995 to R12.4 billion in 2012 and it currently provides nearly 15 per cent of global supply. In terms of the Government's objectives, it would have been preferable if the expansion in exports had been more widespread, thereby assisting in achieving economies of scale in a wide range of components.

There is no doubt that foreign ownership, as opposed to licensing arrangements, has in many cases been critical for vehicle producers to obtain major export contracts but the question is more

43 Similar trends are evident elsewhere. See, for example, Humphrey and Salerno (2000) on the Brazilian and Indian automobile industries and Carrillo (2004) for the Mexican automobile sector.

44 Lorentzen's (2005) case studies provide some examples. See also the Behr case study in box 3 of this study.

45 The case study of the Toyota supplier system in this paper provides an example. See box 2.

complicated for component producers. Prior to the liberalization phase, it is clear that many locally owned firms were heavily constrained in export markets by conditions imposed by foreign licensors. Since then, many firms have been able to renegotiate the terms of their licence agreements. It is nevertheless surprising that data collected by the South African Automotive Benchmarking Club (SAABC, 2006), found that the level of export orientation for foreign and locally owned firms was the same, with both types of firms exporting 17 per cent of their output. At least part of the reason for the surprisingly low orientation towards exports by foreign owned firms is the fact that a number of foreign-owned suppliers have established facilities in South Africa with the sole purpose of supplying component subsystems to domestic assemblers.

On the other hand, a striking difference between foreign owned and domestically owned component firms was the share of imports as a percentage of output. In the South African component sector, affiliates of TNCs imported 53.7 per cent of their requirements, compared with only 29.4 per cent by local firms (SAABC, 2006). The main explanation is that many new foreign component firms are systems integrators, supplying entire sub-assemblies to the vehicle manufacturer. This is more of an assembly than a manufacturing activity. Foreign firms are also clearly less embedded in the domestic economy, although this may also reflect the fact that many of these foreign firms are fairly new and therefore have not yet developed local sources of supply (Black, 2009).

Role of supplier development

In a producer-driven value chain, involving the assembly of large numbers of components, the strategy adopted by the assembler is of key importance. In the development of the automotive industry in Japan, vehicle assemblers such as Toyota played a key role in the development of ancillary firms.[46] Best practice in the automotive industry has increasingly involved assemblers developing closer linkages with component suppliers and providing them with technological assistance, as well as devolving responsibility to them. Large firms have also acted as mentors over the restructuring efforts of smaller firms, while smaller firms have worked collectively to upgrade their capabilities. In the case of the Indian automotive industry, Okada (2004) shows that assemblers created institutional mechanisms, which played an important role in upgrading suppliers.

By the mid 1990s, more cooperative relationships between assemblers and component suppliers had not yet emerged to any significant extent in South Africa, except insofar as the industry was small and personal contacts played an important role. Most component producers did not receive significant assistance from assemblers, and most firms did not see a more significant trend towards closer cooperation. Many regarded the assemblers as expedient and short-sighted for moving swiftly to use foreign components and endangering the long-term viability of the component sector on which the assemblers ultimately depend. But as the Toyota example indicates (box 2), assemblers also sought to upgrade suppliers in certain instances. Liberalization has forced assemblers to specialize and improve their supply base. On the one hand, this may mean increased global sourcing but on the other, it has encouraged assemblers to work to upgrade selected domestic suppliers as indicated in the Toyota example.

Research and development

South Africa's Income Tax Act provides for a 150 per cent deduction of operating expenses for R&D, as well as accelerated depreciation of buildings, machinery and equipment dedicated to R&D. However, expenditure on R&D is very low in the South African automobile industry. There is also significant evidence that as foreign ownership has increased, it has led to a decline in R&D. Gastrow (2008), drawing on the Human Science Research Council's Centre for Scientific, Technological and Innovation Indicators (CeSTII),[47] found R&D accounted for between 1.6 per cent and 2.3 per cent of turnover from 2003 to 2006 with a declining trend. He compares this to 2002 data indicating that international component firms spend on

[46] For an overview of Toyota's relationship with its suppliers at the global level, see Tsuji (2007).

[47] CesSTII carries out South Africa's national R&D survey on behalf of the Department of Science and Technology.

Box 2. Toyota's global production network and supplier development in South Africa

South Africa's largest motor vehicle assembler, Toyota South Africa (TSA), has gone further than most others in developing its own domestic supplier network. While the company has been developing global sourcing, it sees its local suppliers as stakeholders and has had the objective of upgrading their capacity through various forms of assistance, coupled with a detailed system of performance benchmarks. These interventions took a number of forms. For firms within the Toyota group, Toyota SA was very involved in the negotiation of licence agreements to ensure that exactly the right types of technology were secured. Toyota had introduced the Toyota Supplier Assessment system, which benchmarked all suppliers according to a detailed set of criteria. The *kanban* system was being extended and a Suppliers Council consisting of top suppliers had been established. A further initiative was the establishment of a product engineering group consisting of *goshi* teams: engineers, quality specialists and platform teams who worked with suppliers. Toyota's situation changed fundamentally as it developed much closer links with Toyota Motor Corporation and was gradually converted into a global production hub, eventually becoming a full subsidiary in 2007. Incorporation into Toyota's global production system and the transition to world-scale production had important implications for suppliers as the firm was trying to increase local content and was achieving the volumes that made this possible. But at the same time, the number of domestic suppliers was being reduced, and by 2007 consisted mainly of global firms (defined as foreign owned or a domestically owned firm with a technical agreement with a global supplier). In 2002, Toyota had seven platforms with 160 local suppliers. By early 2007 there were only two primary platforms and 75 local suppliers. While local content was hardly changed, the position of suppliers had been transformed with a huge increase in the share of locally produced parts (by value) being sourced from global suppliers. This increased from 41 per cent of locally produced components in 2002 to 82 per cent in 2007.

Source: Black (2011).

Table 10 Summary of expenditure on research and development and training for South African automotive component suppliers, 2003–2006

Indicator	South African average (n=72)					International average (n=72)
	2003	2004	2005	2006	2003–06	2006
R&D expenditure as % of sales	1.5	2.0	1.6	1.5	1.6	3.0
Training expenditure as % of sales	5.0	4.3	4.2	5.0	4.6	7.1

Source: Adapted from Barnes (2009).

average 2.4 per cent of their turnover on R&D. These figures accord with those from the South African Automotive Benchmarking Club (SAABC) as indicated in table 10, which also shows South African firms spending less than their international peers on R&D. There appears to be little improvement in this trend. For 2009, of the 63 component firms in the SAABC database, only 23 had a budget for R&D. For these firms, R&D as a share of turnover was 1.5 per cent in 2009 (Kuriakose et al., 2011: 67). Preliminary figures for 2012–13 for firms in the KwazuluNatal region indicate a further decline.[48] It also appears that very few automotive firms have accessed programmes to support innovation either because they do not think they were helpful or were too difficult to access (Kuriakose et al., 2011; Stijger and Steyn, 2010).

According to CeSTII, vehicle assemblers operating in South Africa were spending 0.5 per cent or less of turnover on R&D (Gastrow, 2008). Gastrow (2008:10) argues that some vehicle makers undertake significant model-specific design in South Africa and even that General Motors South Africa is the design centre for models in African, Middle Eastern and Latin American markets, with these models being almost exclusively designed and developed in South Africa. This is an

48 Personal communication, Justin Barnes.

overstatement but adaptive engineering, testing and some (mostly relatively minor) product development does take place in South Africa. Ironically, increased global integration has tended to reduce domestic product development because of the tendency towards globally standardized designs. To date this has not been replaced by the location in South Africa of significant niche R&D activities for the global market. In the component sector, increased foreign ownership has also led to a decline in R&D in some cases, but caution should be exercised in how this outcome is interpreted. As the example in box 3 indicates, this does not necessarily imply the downgrading of technological capability.

Industry–research collaboration

Industry–research collaboration is generally weak in South Africa (World Bank, 2011). Of 600 firms, from all sectors, surveyed in the National Innovation Survey, only 1.8 per cent considered their links to tertiary institutions and publicly funded research institutes to be important to their innovation activities (World Bank, 2011:6). However, caution should be exercised in interpreting this data. For example, according to the World Economic Forum *World Competitiveness Report*, South Africa ranked twenty-sixth (just behind the Republic of Korea) out of 144 countries in the category of university–industry collaboration in R&D (annex 3, table A3.4). By contrast, South Africa ranked 111th in the availability of scientists and engineers.

A partial explanation of this apparent paradox may be that while on the one hand South Africa possesses a number of high-quality universities, the shortage of scientists and engineers is reflected in a skills premium, making these categories of staff expensive by standards of other middle-income countries. In the automobile industry, university–industry collaborations are of limited importance. In a survey of automotive components firms, Buys (2010) found that those firms do not consider links to universities or research centres to be important for training and R&D. However, there are stronger links with the Council for Scientific and Industrial Research, from which firms can obtain technical support, as well as access to testing services (Kuriakose et al., 2011).

Box 3. Behr: The impact of foreign ownership on research and development, and technological capability

For South African components firms wishing to operate as first-tier suppliers, a foreign equity link either in the form of a joint venture or foreign ownership has become increasingly important both to provide technology and links to global networks. An example is the acquisition in the late 1990s of a group of South African-based firms by the Stuttgart-based Behr Group. Behr is a large German TNC whose major products are vehicle air-conditioning and engine-cooling systems. It is clear that this investment was advantageous for the local operation, which faced the prospect of cutting production and increasingly competing on price in the aftermarket. Local management expected that employment would have fallen and the company would have struggled to maintain its technological edge.

A few years prior to being acquired by Behr, the South African heat transfer division was spending 4–5 per cent of turnover on R&D, significantly higher than most component producers in South Africa. The South African operation had even developed innovative production technology, which had been licensed to the Behr Group. This composite deposition process involved a new method of braising aluminium using a specially developed powder. But this innovative capability was not a significant factor in the decision to make the acquisition, and by 2000 the situation had changed radically. After the acquisition took place, all R&D activity in South Africa was transferred to Germany or shut down. The South African subsidiary only did development work, although its capability for this was expanding, partly due to the high cost of assistance from the parent company. South African management saw this development as positive for two reasons. Firstly, the South African subsidiary was able to focus to a greater extent on its core activities. Secondly, they now had access to cutting-edge R&D. An example of access to this know-how was the huge saving achieved in the course of a short visit from the parent company by a specialist in furnace technology. The Durban plant was set to invest a large amount in a new furnace to increase capacity but by reorganizing the spacing of parts and the adjustment of heating elements they were able to increase the capacity of the existing furnace with no additional investment. Since the acquisition, the management team had remained virtually unchanged and no expatriate staff had been introduced with the exception of technical staff on short term secondments.

Source: Black (2011).

Quality standards and productivity

A key role player in the achievement and maintenance of quality standards is the South African Bureau of Standards (SABS).[49] Established as a statutory body in 1945, SABS plays an important role in the automotive industry. In this sector its major function is to ensure compliance of components and systems with relevant standards and the SABS transportation laboratory is one of 60 such certification bodies in the world. SABS Product Services provides the automotive sector with an independent qualification service required for ISO and other certification.

The South African Automotive Benchmarking Club (SAABC) is a privately funded, not-for-profit initiative established to supply benchmarking services aimed at promoting world-class manufacturing in the automotive components sector. Its main membership is in KwazuluNatal, where it was established in 1997. Member firms contribute and receive benchmarking information and advice.

There have been a number of efforts to establish automotive clusters, and the most successful has been the Durban Automotive Cluster (DAC), which is a partnership between eThekwini Municipality and the automotive industry in KwazuluNatal and plays an important role in promoting learning and productivity among its membership. Another State-supported initiative is the Automotive Industry Development Centre, which operates mainly in Gauteng and the Eastern Cape to promote supplier development.

Training and skills

The education and training system is important for improving absorptive capability. South Africa's deficiencies at school and tertiary level are well known, and the result is high youth unemployment, combined with a shortage of skills (Barnard, 2009; Archer, 2010; Barnes, 2009). Investment in training within firms in the automotive industry is at relatively low levels, compared with international comparators (table 10). The shortage of skills is reflected in the high-skills premium for technicians, artisans, professionals and managers (Barnes et al., 2013). The failure to address the shortage of skills is a significant constraint on technology transfer and upgrading.

The Sector Education and Training Authorities (SETAs) are a major component of the training system. They are funded by a small levy on all employees and cover all major sectors of the economy. The automotive industry is covered by the Manufacturing, Engineering and Related Services SETA (merSETA). The merSETA is responsible for funding training in the sector, mainly through reimbursing firms that undertake training according to approved plans. Substantial resources are devoted to this end and in the year ending March 2013, employer grants and project expenses amounted to R866 million (Merseta, 2012).

The SETA programme has, however, been much criticized for a number of perceived failings, including the failure to disburse funds in the early years, implementation problems and a mismatch between skills provided and those required due an overly State-driven training process (Archer, 2010; Barnard, 2009).

3. 5. Conclusions and policy implications

South Africa has a history of automotive industry development stretching back for 90 years. The experience has been mixed and has important implications for industry policy in emerging markets, especially in countries that are at the early stage of automotive industry development. This section has emphasized the role of national automotive policy and broader national economic policies because they have had such an important impact on structure of the industry and in turn, on the mode of technology transfer.

For the major part of its history, the industry was highly protected. Nearly all vehicles sold in South Africa were locally assembled. Significant development of the components sector also took place. While there was considerable dependence on foreign technology especially via FDI and the licensing of technology to domestically owned firms, there was also substantial autonomous development of capabilities in process technology and to a lesser extent in product technology

[49] See also UNCTAD (2002).

through internal firm-level investment in skills development, R&D and learning by doing. Components firms were heavily engaged in incremental innovation, although part of their technological effort was directed at the problems of low-volume, multi-product production, rather than simply minimizing costs in a mass production environment.

This production structure resulted from high effective rates of protection without accompanying industrial policy measures, which could have prevented the excessive proliferation of models being locally assembled in low volumes. Low-volume assembly makes it extremely difficult for components producers to be competitive. Excessive proliferation can be prevented by ensuring that effective rates of protection for vehicle assembly are not unduly high and by using targeted industrial policy measures. The latter could, for example, include some stipulation about minimum model-production volumes in order to qualify for duty rebates and other incentives. This is an important consideration for all developing countries and perhaps especially for those in the early stages of establishing an automotive industry, such as Nigeria. With hindsight, a more rational industry structure could have been established from the start with the judicious use of industrial policy and subsidies. The East Asian experience of combining protection with export support from an early stage has perhaps been a more effective strategy. Having said this, for countries starting out in the automotive industry, a degree of protection (or other form of support) has been the norm and is usually essential.[50]

Trade liberalization was introduced in a limited way starting in 1989 and then accelerated with the introduction of the MIDP in 1995. This was a major policy shift, and arguably, the import–export complementation policy under the MIDP provided too much support to exporters. Its effect was also to liberalize imports very rapidly, not only because of tariff reductions, but also because the huge volume of import credits generated allowed for the offsetting of import duties on a growing volume of imports of both vehicles and components. In a relatively short space of time, the industry went from being highly protected to becoming very export oriented. This change was driven mainly by automotive industry policy shifts as well as the wider shift towards opening up of the economy following the process of democratization.

Over half the vehicles produced in South Africa are currently exported but it would be an exaggeration to state that the country has established itself as a competitive export platform for the global industry along the lines of Thailand, the Czech Republic or Mexico, for example. While the level of competitiveness of the domestic automotive industry has improved, local content remains relatively low and the supply chain in South Africa is not very strongly developed. Also, South Africa's position, remote from major markets, is a major stumbling block. With the rapid growth being experienced in sub-Saharan Africa, the growing regional market will in due course provide a major new impetus for automotive industry growth.

Throughout this period, it is important to note that the industry has for the most part remained reliant on foreign technology, either through direct investment or by the licensing of technology by domestic firms. At no stage was there a significant effort to develop a domestically owned industry as has been the case in the Republic of Korea or Malaysia. There are no domestically owned vehicle producers. There are also very few domestically owned, first-tier component suppliers, which do not rely on licensed technology from foreign firms. In fact, the strong emphasis on exports under the MIDP accelerated the shift to growing foreign ownership. Domestically owned firms operating using licensed technology were frequently restricted by the licence terms from accessing export markets. Also equity links with foreign partners or outright foreign ownership could open up access to global value chains. Any negative implications arising from foreign ownership have to be tempered by the realization that it has been necessary for the survival of many local firms.

Foreign ownership has implications for R&D in South African-based firms. There is less need for ongoing adaptations of products as they become standardized to global designs. However, foreign ownership brings new technology and easier access to expertise in the high-volume, low-cost production required for global competitiveness. Direct support for R&D may, therefore, be of little benefit to most South African-based automotive

50 See, for example, Humphrey and Oeter (2000).

firms, unless its objectives are clearly specified. However, focused support for R&D could play a role in encouraging TNCs to locate parts of their R&D investment in South Africa.

While the automotive industry is one of the largest manufacturing subsectors in South Africa and has received considerable Government support, the impact of national STI policies has been limited for a number of reasons. The most important is probably the large (and increasing) role played by foreign firms. Upgrading and technology transfer in this environment tends to be driven more by the investment decisions of TNCs, which have been much more a function of the level of production and the incentive structure created by the MIDP and the APDP than of existing STI policies. In contrast to many other manufacturing industries in the country, the lack of very large local firms in the South African automotive industry means that, in spite of its importance to the economy, the sector is not at the centre of indigenous technology development.

A second factor, which relates to the above, is that high rates of investment in capital equipment, training and R&D by foreign and domestic firms are fundamental to rapid technology transfer and upgrading. This has not been achieved on a consistent basis in the South African automotive industry.

A third factor is that the STI institutional infrastructure is rather weak, characterized by a lack of coordination between the various programmes and agencies and a lack of clear objectives. The role of TNCs has become a major determinant of the trajectory of upgrading, and these institutional weaknesses mean that there is little additional support for upgrading outside those provided by TNCs operating locally. The poor performance of the education and training system at all levels in South Africa is especially problematic in creating an environment more appropriate to rapid upgrading. So while the automotive industry has received lavish support in terms of production, export and investment incentives, other forms of institutional support (from state or other agencies or from universities) have been much more limited.

Future reviews of national policies by the South African Government might seek to reduce reliance on these generic production incentives while strengthening the institutional infrastructure to promote technology transfer and upgrading in the automotive industry. Especially critical in the South African context is the development of a system of training and skills provision which not only dramatically steps up the provision of skills, but ensures that they are appropriate to industry requirements for upgrading.

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Annex 3

Table A3.1 Dollar–rand exchange rate, 1995–2012

Year	$ per South African rand
1995	0.28
1996	0.23
1997	0.22
1998	0.18
1999	0.16
2000	0.14
2001	0.12
2002	0.10
2003	0.13
2004	0.16
2005	0.16
2006	0.15
2007	0.14
2008	0.12
2009	0.12
2010	0.14
2011	0.14
2012	0.12

Source: http://www.oanda.com/currency/average.

Table A3.2 Employment in the South African automotive sector, 1995–2012

	Assembly	Component	Tyre	Motor trade	Total
1995	38 600	65 500	11 000	178 000	293 100
1996	38 600	65 600	10 000	180 000	294 200
1997	37 100	69 100	9 500	180 000	295 700
1998	33 700	69 700	9 100	170 000	282 500
1999	32 000	67 200	6 670	175 000	280 870
2000	32 300	69 500	6 575	180 000	288 375
2001	32 700	72 100	6 300	182 000	293 100
2002	32 370	74 100	6 000	185 000	297 470
2003	31 700	75 000	7 200	191 000	304 900
2004	31 800	74 500	7 200	194 000	307 500
2005	34 300	78 000	6 800	198 000	317 100
2006	39 000	80 000	6 900	199 000	324 900
2007	38 300	81 800	6 800	201 000	327 900
2008	35 900	74 000	6 200	200 000	316 100
2009	30 100	61 000	5 700	203 000	299 800
2010	28 128	65 000	6 600	200 000	299 728
2011	28 147	68 500	6 500	200 000	303 147
2012	30 159	70 000	6 500	200 000	306 659

Source: NAAMSA Annual Reports (various years); *Automotive Export Manual* (various years).

Table A3.3 Technical parameters of MIDP, 1995–2012

				Value of export performance			Ratio of exports vs. imports			
Year	CBU duty %	CKD duty%	DFA %	CBU %	Components %	Qualifying PGM value %	HCV and tooling and components vs. CBU LV	Vehicle and tooling and components vs. HCV and tooling and components	CBU LV vs. CBU LV, HCV and Tooling and components	PAA/AIS %
1995	65	49	27	100	100	100	100:75	100:100		—
1996	61	46	27	100	100	100	100:75	100:100		—
1997	57.5	43	27	100	100	100	100:75	100:100		—
1998	54	40	27	100	100	100	100:75	100:100		—
1999	50.5	37.5	27	100	100	90	100:75	100:100		—
2000	47	35	27	100	100	80	100:70	100:100		20
2001	43.5	32.5	27	100	100	60	100:70	100:100		20
2002	40	30	27	100	100	50	100:65	100:100		20
2003	38	29	27	94	94	40	100:60	100:100		20
2004	36	28	27	90	90	40	100:60	100:100		20
2005	34	27	27	86	86	40	100:60	100:100		20
2006	32	26	27	82	82	40	100:60	100:100		20
2007	30	25	27	78	78	40	100:60	100:100		20
2008	29	24	27	74	74	40	100:60	100:100		20
2009	28	23	27	70	70	40	100:60	100:100		20–30
2010	27	22	27	70	70	40	100:60	100:100		20–30
2011	26	21	27	70	70	40	100:60	100:100		20–30
2012	25	20	27	70	70	40	100:60	100:100		20–30

Source: AIEC.
Notes: CBU – completely built up; CKD – completely knocked down; DFA – duty free allowance; PGM – platinum group metal; HCV – heavy commercial vehicle; LV – light vehicle; PAA – productive asset allowance; AIS – automotive investment scheme.

Table A3.4 Global competitiveness indices for South Africa and comparator countries, selected indicators, 2012 ***(Ranking out of 142)***

	South Africa	China	Thailand	Russian Federation	Republic of Korea	Germany	Japan	United States
GDP/capita $ (2010)	7 158	4 382	4 992	10 437	20 591	40 631	42 820	47 284
Global competiveness index 2011–2012	50	26	39	66	24	6	9	5
Higher education and training	73	58	62	52	17	7	19	13
Tertiary education enrolment, gross %	97	85	54	13	1	n/a	35	6
Quality of management schools	13	59	73	107	50	36	57	12
Technological readiness	**76**	**77**	**84**	**68**	**18**	**14**	**25**	**20**
Firm-level technology absorption	30	61	75	130	8	14	3	18
Internet users/100 pop.	105	75	93	57	10	12	15	18
Innovation	**41**	**29**	**54**	**71**	**14**	**7**	**4**	**5**
University–industry collaboration in R&D	26	29	39	75	25	13	16	3
Availability of scientists and engineers	111	33	49	72	23	41	2	4

Source: World Economic Forum (2012).

Chapter 4. Technology transfer and the development of biotechnology in Argentina

Introduction

Biotechnology, the use of biological organisms to develop commercial applications, is one of the three sets of generic technologies[51] that are revolutionizing a wide range of industries. Biotechnologies are used in agriculture, as well as in the chemical, environmental, pharmaceutical and other sectors. These technologies were originally developed in the United Kingdom and the United States, and the latter soon took the global lead in its commercial applications. Yet, biotechnology capabilities have also slowly developed in Canada, continental Europe, and Japan, and more recently in emerging economies in Asia and Latin America.

This case study will briefly retrace the adoption of biotechnologies in Argentina and the development of domestic biotechnological capabilities in the main applications of human and animal health and agriculture to identify the main channels through which the private sector has adopted this technology in its productive activities.

4. 1. The biotechnology sector in Argentina

Like other industries or technologies, Argentina started very early adopting biotechnology science and applications in different products. The reasons for such early start were many. In the first place, since the late 1800s, Argentina had benefited from a massive influx of European immigrants, including a good number of scientists. This immigration explains the fact that Argentina has had three Nobel Prizes in medicine or physiology (A. Houssay, C. Leloir and C. Milstein). In 1984, Milstein was awarded a Nobel Prize for his discovery (together with Georges Kohler) of the technologies required to produce monoclonal antibodies. Even if the rate of growth of scientific publication in Argentina is not excessively rapid, it remains the main producer of scientific knowledge in the region, including in biotechnology, when one considers its smaller population and number of researchers (table 11).

Another major element explaining the fast adoption of biotechnology in Argentina was the presence of a generic pharmaceutical industry and a highly productive and extensive agricultural sector, both of which are eager users of biotechnology.

The biotechnology sector of Argentina is composed largely of domestic firms – both dedicated biotechnology firms and diversified firms that have engaged in biotechnology activities – and a number of subsidiaries of foreign TNCs. The Second National Survey of Biotechnology Firms in Argentina (Anlló et al., 2011) had identified 120 firms that in 2008–09 were using biotechnology techniques to produce goods or services in the animal and human health area, in agriculture and in the industrial inputs sector (table 11). These biotechnological firms comprised dedicated biotechnology firms (DBFs) as well as seed producers, pharmaceutical and industrial companies. Their biotechnology revenues amounted to 3.1 billion pesos (approximately $925 million) and their biotechnology exports to $261 million. While 98 per cent of these firms were of local origin, nearly half of the biotechnology revenues came from TNCs, mostly in the seed sector.

Another study (Gutman 2010), which only reports biotechnology firms that innovate in processes or products, identified 74 biotechnology firms in Argentina in 2010 and a large participation of TNCs (table 12).

Private biotechnology firms in Argentina are mostly concentrated in the areas of human and animal health, followed by agriculture. Besides academia and the local pharmaceutical sector, Argentina's biotechnology R&D is mostly conducted in locally owned and controlled DBFs. There are no foreign controlled DBFs in the country. On the other hand,

[51] The other ones being information and communications technologies and nanotechnologies.

Table 11 Biotechnology firms in Argentina, 2008–2009: Revenues, exports, and research and development-related expenditure and employment

		Biotechnology revenues		Biotechnology exports	R&D expenditure		R&D expenditure / revenues	Biotech employment	I+D employment	R&D/ Biotech employment
Activity area	Number of firms	All firms	Multinational fims	All firms	All firms	Multinational firms	All firms	All firms		
Human health	24	80.4	-	43.7	11.6	-	14%	709	210	30%
Assisted human fertilization	22	34.3	-	-	0.5	-	1%	137	107	78%
Animal health	6	62.4	-	5.8	1.8	-	3%	317	25	8%
Animal reproduction	14	4.3	-	0.1	1.5	-	34%	160	53	33%
Seeds	14	637.1	379.5	157.9	29.3	10.0	5%	1'146	305	27%
Inoculants	29	50.0	12.2	8.6	1.2	0.3	2%	423	65	15%
Micropropagation	6	2.5	-	0.2	0.4	-	18%	82	24	29%
Industrial inputs	5	53.1	44.3	44.9	0.1	-	0%	152	12	8%
Total	**120**	**924.0**	**435.9**	**261.2**	**46.3**	**10.3**	**5%**	**3'126**	**801**	**26%**

Source: Anlló et al. (2011) based on the Second National Survey of Biotechnology Firms in Argentina, office of the Economic Commission for Latin America and the Caribbean in Argentina. Exchange rate used: 1 dollar = 3.4 Argentine pesos.

Table 12 Biotechnology firms in Argentina by sector and type of enterprise, 2010

	New biotechnology firms	National dedicated biotechnology firms	National diversified firm	TNC	Total
Human health	6	9	11	1	**27**
Animal health	—	5	11	—	**16**
Agriculture	2	2	5	12	**21**
Industrial inputs	1	1	4	4	**10**
Total	**9**	**17**	**31**	**17**	**74**

Source: Gutman (2010).

Notes: New biotechnology firm: a firm specialized in biotechnology of recent establishment. Often a spin-off or a start-up operating in alliance with other biotechnology firms.

National dedicated biotechnology firm (DBF): national firm specialized in biotechnology. These are business services firms that conduct R&D and transfer their knowledge to industrial and agricultural companies.

National diversified firm: a long-established domestic firm that has engaged in biotechnology as an additional production/research line (but not as its main productive activity). These are often pharmaceutical firms that engage in the use of biotechnology for the production of goods or services.

TNC: A subsidiary of a biotechnology transnational company that carries out in the country some productive activity, R&D and/or product adaptation.

the role of transnationals is particularly important in the seed industry, both in terms of number of firms, and revenue and investment in R&D.

The next two sections provide a more detailed description of the health and agricultural biotechnology sectors.

Human and animal health

Argentina was an early adopter of biotechnology for human health. In the 1980s, one domestic company, Sidus, was already producing recombinant insulin. Several other companies followed a few years later. The reasons that Argentina had such an early start were two. On one hand, the country had nurtured for decades a generic pharmaceutical industry through its 1864 patent law that protected processes (that usually companies keep secret) but did not allow protection for products (Chudnovsky, 1979). Such a strategy, similar to those implemented by Brazil, China, India and Turkey, allowed the country to build technological capability while at the same time serving local and neighbour markets with price-accessible drugs. Argentine firms copied existing biotechnology products, but had yet to rediscover the processes through which these products (mainly drugs and GMOs) were made. In the mid-1990s, several pharmaceutical TNCs acquired local firms, and a few new manufacturing plants were established. Some manufacturing technologies were transferred to Argentina through FDI. The December 2001 crisis and debt default triggered the exit of the TNC, the consolidation of the domestic producers and the expansion of exports in order to compensate for revenues lost in the domestic market. Some manufacturing technologies thus changed hands, and Argentine firms acquired these technologies through the acquisition of TNC operations. These domestic pharmaceutical companies, including Bagó, Roemmers, Gador, ELEA, Biosidus, Cassará and Raffo, either acquired domestic independent biotechnology firms and/or entered into alliances and technology agreements with them.

Several pharmaceutical private companies in Argentina are moving from the production of generic drugs to the much more complex biopharmaceutical medicines (table 13). So far, they have only aimed at producing biosimilar products, that is, domestic versions of drugs that have been developed elsewhere and have lost patent protection – versions such as recombinant insulin, human and animal growth hormones, interferon and monoclonal antibodies. By 2012, several domestic companies were producing first-generation recombinant products and were preparing the launching of follow-on monoclonal antibodies.

Table 13 Health biopharmaceutical companies in Argentina and their products

Domestic bio-pharmaceutical firm	Biotechnology products in the market
AMEGA Biotech (majority controlled by Roemmers)	Human cytokines, recombinant cells, monoclonal antibodies
BETA Laboratorios	Recombinant human insulin
Biocientifica	Kits for the detection of antibodies in autoimmune diseases; anti sera for human proteins developed in goats
Biogénesis-Bagó (joint venture of Bagó and Chemo)	Recombinant foot and mouth vaccine
Bioprofarma	Erythropoietin, fylgrastim, interleukin, interferon alpha 2a and 2b, irinotecan, molgramostim
Bio-Sidus (Sidus Group)	Erythropoietin, fylgrastim, human growth hormones, recombinant insulin, human antithrombin and somatropin. Cloned cows producing recombinant human insulin
Cassará Laboratorios	Erythropoietin, fylgrastim, interferon alpha and beta, interleukin, molgramostim (gm-CSF), recombinant hepatitis B vaccine, proteins
Chemo Group	Phase III assays for new molecular antibodies for breast and lung cancer; phase II assays for new peptides against uterine cancer and breast cancer
Craveri Laboratorios	Human tissue
ELEA	3TC/AZT, erythropoietin, diagnostic kit for diabetes using recombinant proteins, recombinant tyrosine phosphatase
LKM	Interferon, monoclonal antibodies against cancer
PC Gen	Erythropoietin, interferon alpha 2a, and 2b
PolyChaco	Biotechnology diagnostic kits for Chagas disease
Purissimus Labs	Human blood derivatives
Wiener Laboratorios	Biotechnology diagnostic kits for Chagas disease and hepatitis B and C; sera-based monoclonal antibodies
Zelltek (Amega / Roemmers)	Erythropoietin

Source: Niosi, based on personal interviews.

Chemo is the only private large pharmaceutical company that is conducting advanced research on biopharmaceutical drugs. It is the leading member of an international consortium involved in the development of a new-to-the world monoclonal antibody. Even if its head office has since 1977 been located in Barcelona, Spain, its main shareholders are members of an Argentine family headed by Hugo Sigman and Silvia Gold. Chemo has pharmaceutical operations and conducts R&D in Argentina, India, Italy, and Spain. The group is close to launching its own line of (biosimilar) recombinant proteins and monoclonal antibodies in Argentina through its biopharmaceutical subsidiary Sinergium Biotech. In 2012, Sinergium inaugurated a new pharmaceutical plant in the province of Buenos Aires devoted to the production of biosimilars and received technology from both Novartis and Pfizer.

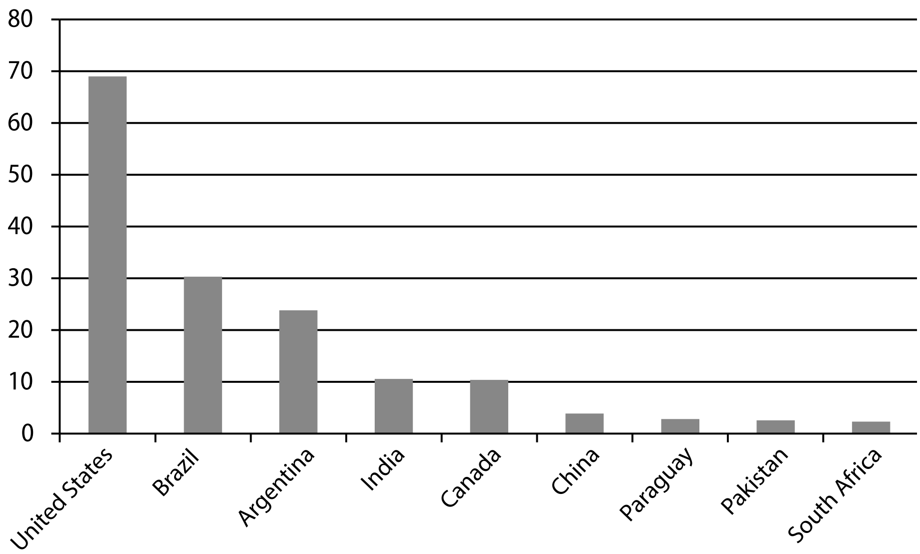
These private firms, owned and controlled by families in Argentina, are investing in biopharmaceutical products through the reinvestment of their own revenues. The public financial support they have received has been limited.

Agricultural biotechnology

The impact of biotechnology on the Argentine pharmaceutical industry is just unfolding. On the contrary, the impact of the adoption of genetically modified (GM) seeds for agriculture is evident in the volume and the value of production and exports of agricultural GM products. Since the mid-1980s, Argentina has been an early adopter of GMOs for some of its main crops, including soybeans, maize and cotton. The reasons are many, including government support to the new seeds through modest R&D efforts conducted in INTA and several public universities, public approval of biotechnology and the existence of a global demand for these products. The area planted with these varieties has increased very fast since 1986. Today, Argentina is the third global producer of biotechnology crops after the United States and Brazil, and before Canada, China and India (figure 8 and table 15).

GM seeds were originally acquired from large transnational corporations such as Bayer, Dow, Monsanto, Pioneer and Syngenta. Monsanto's seeds were licensed to an independent company, Asgrow, in the late 1980s. In 1989, an Argentine transnational trading firm, NIDERA, acquired Asgrow and massively introduced transgenic soybeans in Argentina. From then on, a black market of GMOs took off in the country (USDA, 2009). Illegal exports of GM seeds from Argentina to the Plurinational State of Bolivia, Brazil, Paraguay, and Uruguay have stimulated the adoption of transgenic crops in these countries.

Figure 8 Millions of hectares of transgenic crops in main countries, 2010



Source: Nature Biotechnology, March 2012, p. 207.

Table 14 Main genetically modified crops in selected countries, 2012

Rank	Country	Transgenic area (million HA)	Main crops	Region
1	United States	69.0	Maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash	North America
2	Brazil	30.3	Soybean, maize, cotton	Latin America
3	Argentina	23.8	Soybean, maize, cotton	Latin America
4	India	10.6	Cotton	Asia
5	Canada	10.4	Canola, maize, soybean, sugar beet	North America
6	China	10.4	Cotton, papaya, poplar, tomato, sweet pepper	Asia
7	Paraguay	2.8	Soybean	Latin America
8	Pakistan	2.6	Cotton	Asia
9	South Africa	2.3	Maize, soybean, cotton	Africa
10	Uruguay	1.2	Soybean, maize	Latin America

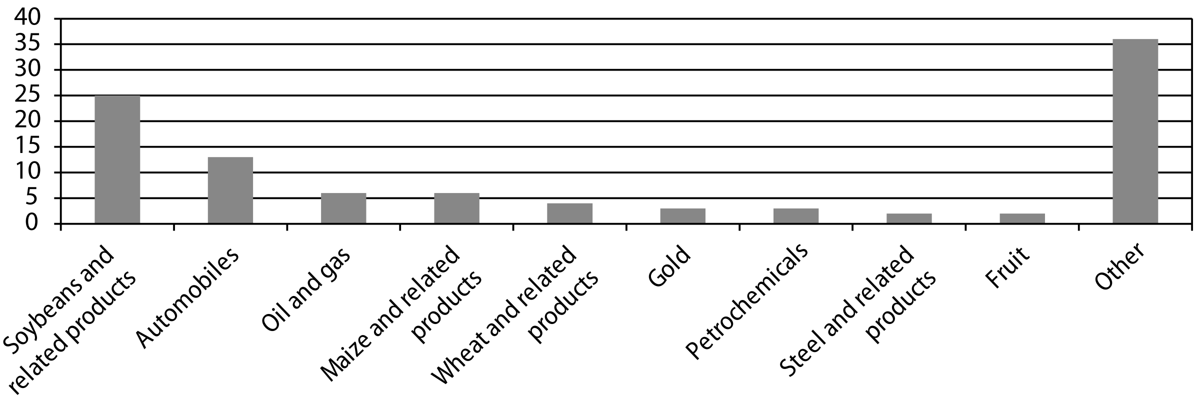
Source: Nature Biotechnology, March 2012, p. 207.

Argentina's GMO production and exports, whether in the form of flours for animal feed, oils or grain, are increasingly concentrated in soybean products and grain (figure 9). While in 1996 some 26 per cent of Argentina's agricultural land was planted with soybeans, in 2011, soybeans (almost 100 per cent GMOs) covered some 56 per cent of Argentina's cultivated land. The exports of soybeans grain and products represented over $21 billion, almost 25 per cent of the country's sales to the world. When maize and wheat are added, GMO production represent well over one third of Argentina's exports (table 14).

In addition to having only a limited number of GM crops, only few new traits have been introduced in the GM crops cultivated in Argentina, mainly herbicide tolerance and biotechnological resistance to insects (Qaim, 2005).

The diffusion of agricultural biotechnologies has mainly taken place through the technological packages built around GM seeds, which also include specific agricultural inputs (herbicides and inoculants) and productive techniques (direct planting). The subsidiaries of TNCs have played a key role in this process. In 2010, Gutman (2010) identified 21 biotechnology firms providing inputs and services for the agricultural sector. More than half of the agricultural biotechnology firms were subsidiaries of foreign transnationals. These subsidiaries were concentrated in, and

Figure 9 Argentine exports by main group of products, 2011



Source: www.informeindustrial.com.ar/Secciones.aspx?Seccion=Comercio-exterior___11&pagina=1

Table 15 Biotechnology firms in the agricultural sector Argentina by type of enterprise and type of product, 2010

Type of firm	Type of product				Number of firms
	GM seeds	Seedlings, micropropagation	Inoculants	Others	
New biotechnology firms	1	1	—	—	2
National dedicated biotechnology firms	—	1	1	—	2
National diversified firm	2	—	-	3	5
TNC	8	-	3	1	12
Total number of firms	11	2	4	4	21

Source: Gutman (2010).

represented the majority of providers of GM seeds and inoculants. Only 9 domestic agricultural biotechnology firms were identified and barely 3 of them worked in the provision of GM seeds (table 15).

Stronger local biotechnology R&D capabilities are crucial are for several reasons. First, to be able to increase competition in the provision of seeds and, thus, reduce the cost and imports of agricultural inputs. Local R&D capabilities are equally needed be able to support the introduction of other traits relevant for local agricultural environments (e.g. drought resistance) and to facilitate the development of other GM plant varieties more adapted to Latin American markets and consumer tastes. TNCs often have limited economic interest in investing in the development of such traits and varieties.

4. 2. Argentina's biotechnology innovation ecosystem

The emergence of the biotechnology sector in Argentina has taken place in an ecosystem of institutions (figure 10) that, to varying extents and with different impact, provide the human resources base and R&D infrastructure for the financing of biotechnology R&D and have influenced the adoption of these technologies through national policies and regulatory approaches.

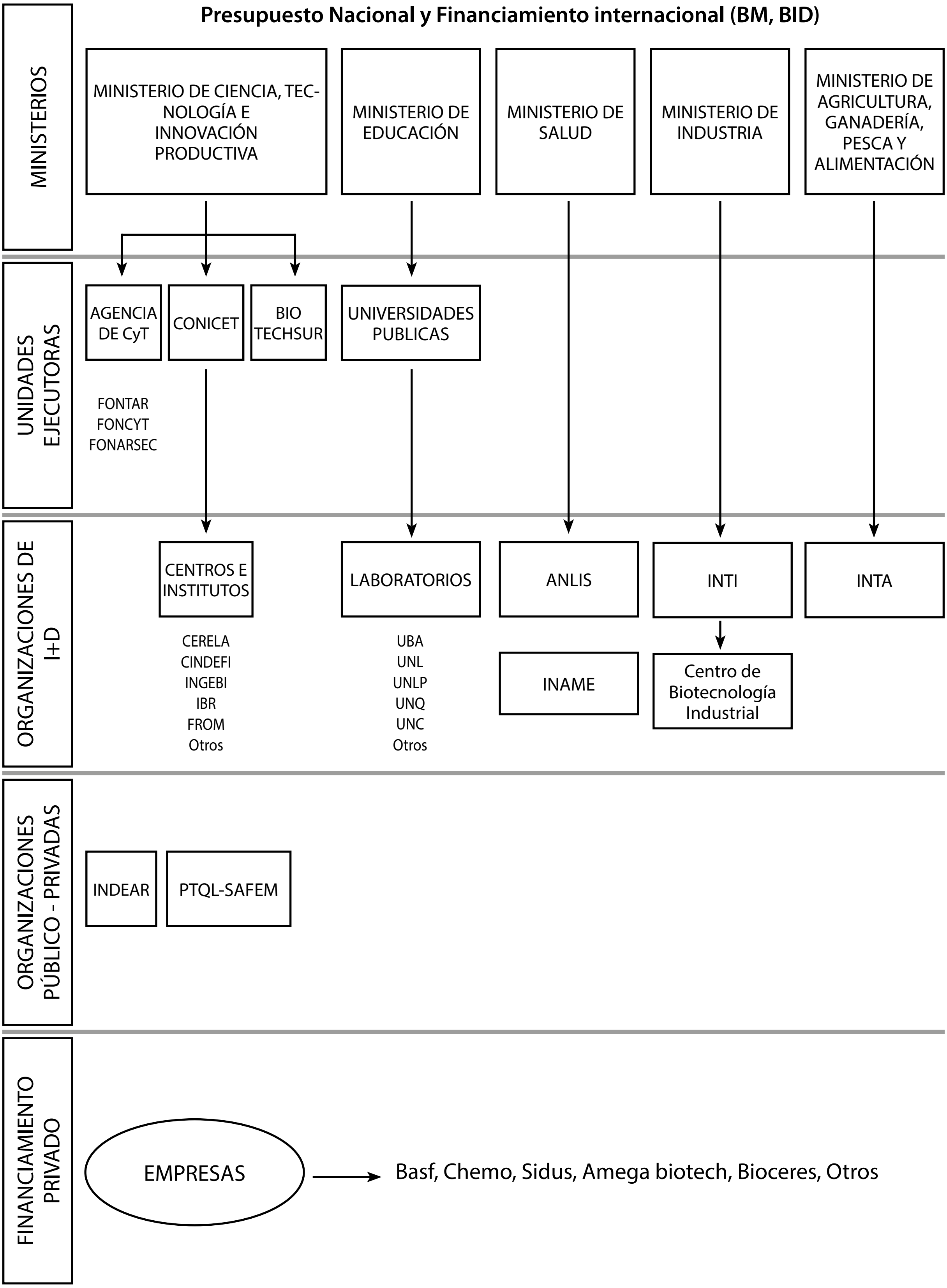
The following sections present a number of key elements of this ecosystem that have had a major bearing on the transfer of biotechnologies in the country.

Research and patenting capabilities in biotechnology

Argentina's research and patenting capabilities in biotechnology are, together with Brazil, among the most advanced in the region. Up to the year 2000, Argentina and Brazil were on similar grounds in terms of biotechnology patents and publication; since then Brazil has become a major publishing force and keeps growing in patents. However, even if Argentina's publication activity in biology, biochemistry, biomedical science and related disciplines is growing, South-East Asian countries are increasing their research capabilities (in terms of publications) much faster than any other Latin American country and are having a greater scientific impact (Hermes-Lima et al., 2007) (table 16).

The same phenomenon is visible in the commercial application of biotechnology. Argentina's first United States biotechnology patent was granted in 1984, the same year the Republic of Korea received its first one. By 2011, Argentina's assignees had been granted a total of 20 United States biotechnology patents, against close to 1000 United States patents held by organizations from the Republic of Korea. By 2011, organizations from Singapore (population, 4.7 million) had been granted 143 United States biotechnology patents, more than all Latin American countries combined table 17).

Figure 10 Argentina's biotechnology innovation ecosystem



Source: Gutman (2010).

Table 16 Publications in biotechnology: Articles published in Latin America and South-East Asia, 1996–2011

Country	Population 2011	Agricultural biotechnology articles	Health biotechnology articles	Total biotechnology articles	Total articles per million population
Argentina	41	781	1 872	4 038	98
Brazil	201	3 965	7 301	17 591	36
Chile	17	411	761	2056	48
China	1 330	12 344	46 166	89 762	67
India	1173	8 424	8 058	30 477	26
Mexico	112	1 243	1 843	5 225	47
Singapore	5	309	2 918	5 279	1 056
Republic of Korea	49	3 980	11 060	26 640	547

Source: Scopus.

Table 17 United States biotechnology patents: Latin America and South-East Asia compared, 1978–2011

Country	Patents with local inventors (inventiveness)	Patents with local assignees (ownership)	Patents with local assignees per million population (2011)
Argentina	97	20	0.5
Brazil	186	69	0.3
Chile	37	16	0.9
China	485	254	0.2
India	528	367	0.3
Mexico	119	33	0.3
Singapore	198	143	29
Republic of Korea	1 205	960	20

Source: USPTO.

A wide range of public universities (primarily the largest universities of Buenos Aires, La Plata, Cordoba and Litoral) and public research organizations (CONICET, INTA, ANLIS and their research centres) conduct research in biotechnologies (table 18). Argentina's patents and publications relating to human and animal health biotechnology are mostly concentrated in the largest national universities (Buenos Aires, La Plata, Cordoba and Litoral). INTA and INTI own a number of domestic patents but no United States patent.

Argentina's continued policy support for biotechnology

Argentina has established several plans aimed at developing biotechnology. The National Programme for Biotechnology (1982–1991) supported several projects. Between 1992 and 1996, a priority national plan for biotechnology was implemented. The Biotechnology Programme of the National Plan for Science and Technology (1998–2000) and the National Strategic Plan for Science, Technology and Innovation (2006–

Table 18 Scientific articles on biotechnology published by main institutions in Argentina, 1996–2011

Institution	Number of articles
CONICET	1 720
National University of Buenos Aires	1 024
National University of La Plata	537
INTA	318
National University of Cordoba	232
National University of Tucumán	178
National University of Rosario	168
National University del Sur	140
National University of Litoral	137
National University of Quilmes	120
National University of G. San Martín	117
National University of Mar del Plata	106
National University of San Luis	91
ANLIS	85
Fundación Leloir	84
National University of Rio Cuarto	72
National University of Comahue	62
CNEA	58
National University of Salta	46

Source: Scopus.
Note: Some articles have multiple authors from different source institutions and are counted several times.
Abbreviations: CONICET – National Council for Scientific Research
INTA – National Institute for Agricultural Technology
ANLIS – National Administration for Health Laboratories and Institutes
CNEA – National Atomic Energy Commission

2010) followed. Other instruments promoting biotechnology development include the 2007 Law (26.270/07) on Promoting the Development and Production of Modern Biotechnology, which provides tax incentives for R&D projects, the production of goods and/or services and new ventures developed domestically; as well as the Stimulus Fund for seed capital.

Argentine policies have also encouraged the adoption of agricultural biotechnology. In 2005, Argentina issued the National Strategic Plan for Agricultural Biotechnology (Argentina, 2005), stretching from 2005 to 2015, where GMOs were presented as a solution to both agricultural productivity and export earnings. The Argentine Government has defended the use of GMOs in domestic agriculture in every national and international forum. Unlike other countries, the debate about transgenic crops in Argentina has been modest. Academia, farmers and the Government largely consider that the benefits of transgenic crops in the form of higher productivity and exports outweigh their negative aspects (massive herbicide imports, deforestation, loss of biodiversity, land concentration and decreasing employment for agricultural labour) (Newell, 2009).

However, such public backing for agricultural biotechnology has not been accompanied with strong support for the development of local agricultural biotechnological capacities in GMOs, as indicated by the limited presence of domestic biotechnology firms in this sector and the very limited number of biotechnology patents. For instance, between 2000 and 2007, Argentina registered only three agricultural biotechnology patents in the United States with Argentine assignees.[52] The efforts of the National Institute for Agricultural Technology (INTA) to produce new GMOs have been inhibited by the reduced R&D investments of public agricultural laboratories.

Insufficient public financing of biotechnology research and development

There is no official data regarding the amount of public investment in biotechnology R&D, but this seems to have been limited. As a broader reference between 1996 and 2010, all health-related public expenditures on R&D represented less than $ 200 million annually (as reported by Red Interamericana de Indicadores de Ciencia y Tecnología, RICYT, on the basis of official figures).[53]

Public investment in biotechnology R&D has largely taken place through the financing of research and infrastructure in universities and research organizations. The public funding of human health biotechnology research in the country is concentrated in one agency, the Agencia Nacional de Promoción Científica y Tecnológica, through different funds called FONCYT, FONTAR and

52 Biotecsur (2007).
53 www.ricyt.org.

FONARSEC. Besides, public funds have also helped establish biotechnology centres at the National Institute for Agricultural Technology (INTA), which is hosting today some 120 researchers, and at the National Institute for Industrial Technology (INTI), which in 2011 had expanded its biotechnology laboratory to some 20 researchers.

The amount of public funding devoted to supporting private investment in R&D biotechnology has been very limited. For instance, FONTAR has distributed a total of $22 million (estimated at 2003 constant values) during the period 1995–2010.[54] The one-off FONARSEC funds for biotechnology firms set up by in 2010 assigned a total of $23.2 million. FONCYT funds are not available for private firms. Annex 4 provides more details on the main programmes through which national government funds are channelled to support private investment in biotechnology R&D.

Most of the national government funds channelled to biotechnology firms have been allocated to the human health sector followed by the animal health sector. For instance, 94 per cent of the funds disbursed by FONTAR between 1995 and 2010 were for the human and animal health sectors (75 per cent and 19 per cent, respectively). Only 10 per cent of the funds were earmarked for the agricultural sector. The two biotechnology-specific funds for firms set up by FONARSEC in 2010 allocated $17.3 million to carry out research in human health, $1.5 million in animal health and $2.9 million in agriculture.

Regulatory framework supporting imitative strategies

In the area of human health, Argentina has issued fairly soft regulations with fewer constraints than many other countries.[55] For example, any company wishing to introduce a biosimilar product needs to demonstrate its bioequivalence (similar molecular structure, similar pharmacokinetics) with a reference drug (i.e. an existing product already approved in the United States or Western Europe) and register it in Argentina. Only efficacy and safety need to be demonstrated for that product (Kirchlechner, 2011; UNCTAD, 2011). Thus, Argentina gives approval to follow-on biologics with relatively limited clinical trials and the demonstration of biological similarity with respect to existing original drugs. But as these biosimilars are complex products – for instance, few successful clinical trials can hide major differences in the structures of the large macromolecules– a number of countries have a more stringent process for the approval of biosimilars – (at least for more complex molecules). Under these conditions, Argentina's biotechnology drugs can only be exported to other countries with similar soft regulation. UNCTAD (2011) argues that Argentina's regulatory practice of approving drugs by similarity and the requirement that bioequivalency tests be conducted only on high-risk drugs, and antiretrovirals have contributed to the preservation of a competitive pharmaceutical market in the country and favours new entrants and high levels of competition in the generic drug market. However, there have been legal challenges to this system that argue that it is incompatible with the TRIPS agreement (see UNCTAD, 2011 for details).

Argentina's biotechnology policy in agriculture has mostly taken place through the regulatory system. The National Commission for Agricultural Biotechnology (CONABIA) studies the effects of new GMOs on the environment. Any new GMO needs the approval of CONABIA. Another organism (SENASA, or, National Service for Health and Agricultural Quality), assesses the food characteristics of any new GMO before it is released. Finally, the National Direction of Agricultural Markets (DNMA) evaluates the benefits of its market entrance. The country does not regulate the use of imported GMOs, but tends to approve the varieties that international seed corporations bring to the country. Thus, seeds have been imported for alfalfa, cotton, maize, potatoes, rice, soybeans, sunflower, wheat and a few other crops. Yet these crops were genetically engineered with two main considerations: their usefulness in North American agriculture and their profitability for the seed companies.

In this sense, the biotechnology regulatory policy has facilitated the diffusion of modern biotechnology in the country, both in agricultural biotechnology and in health applications, although so far it has only predisposed Argentina to be a passive adopter of modern biotechnology.

[54] Ministerio de Ciencia, Tecnología e Innovación Productiva (2012).

[55] See UNCTAD (2011) for details on the Argentine drug manufacturing, importing, exporting and marketing system.

4. 3. Modes of technology transfer

Biotechnology has diffused in Argentina through several channels: local academic research, the acquisition of technology and GM seeds from foreign private firms, foreign direct investment, the acquisition or establishment of dedicated biotechnology firms, R&D collaboration between the industry and research organizations, and the hiring of university graduates by local firms.

Local academic research and development and international collaboration

Academic research, often conducted in collaboration with foreign institutions, has been a main channel for technology transfer. As mentioned in section 3, Argentina's research capabilities in biotechnology are, together with Brazil, among the most advanced in the region. International scientific cooperation is evident in the number of co-authorship in biotechnology articles. The patterns of co-authorship show that Argentine academics collaborate mainly with OECD countries. They are, in descending order, as follows: the United States, Spain, Germany, France, the United Kingdom, Italy, Japan and Canada (table 19). These research collaborations are the main channel of technology transfer.

Table 19 Co-authorship of scientific articles between Argentina and main countries, 1996–2008

Country of residence of co-authors	Co-authored articles	
	Number	Percentage
United States	311	29
Spain	161	15
Germany	100	9
France	95	9
United Kingdom	75	7
Italy	44	4
Japan	44	4
Canada	39	4
Total, 8 main countries	869	81
All other	198	19
Total	**1 067**	**100**

Source: Scopus.

These countries represent most of the main producers of biotechnology knowledge. One caveat is China, which has become one of the largest producers of biotechnology knowledge in the last 10 years, and with which Argentine academics do not tend to collaborate with. Conversely, they collaborate substantially with Spanish scientists. In both cases, cultural affinity (or lack of) is to be pointed out as the main explanation. Similarly, Brazil academics tend to cooperate with Portuguese scientists but not with their Chinese colleagues.

FONTAR's ANR and FONCYT's PID programmes have encouraged collaborative research and have also aimed at increasing university research and making academic results more relevant for the industry.

Buying genetically modified seeds and technology from foreign private firms

The acquisition of technology (whether in the form of laboratory equipment or genetically modified seeds) provides a second inward channel of technology transfer.

For over a century, Argentine agriculture has been exporting to the richest European countries and adopting agricultural technologies from North America and Europe. Similarly, Argentina has been an earlier adopter of agricultural biotechnologies, such as genetically modified seeds and their related inputs and farming techniques.

The acquisition of foreign technology equipment for laboratories and manufacturing (such as the acquisition of drug manufacturing plants from foreign transnationals installed in Argentina; see section 4.3) has also been a fundamental element for the formation and development of manufacturing and research capacity in the country.

Foreign direct investment

While most R&D is currently conducted by national firms, FDI in the pharmaceutical sector has enabled the transfer of manufacturing technologies and technological know-how to Argentina. Several factors have allowed such transfer of technology through FDI. First, the existing technological capabilities of the local generic pharmaceutical industry, which had been built through imitation activities favoured by the Argentine 1864 patent law that protected processes but not products. Second, a rise in FDI in Argentina and the establishment of new manufacturing plants in the country. And, third, the exit of TNCs from the country (triggered by the 2001 crisis and debt default) and the consolidation of domestic generic drug producers that acquired some of the pharmaceutical manufacturing plants as TNCs disinvested in the country.

Acquisition or establishment of dedicated biotechnology firms

Another channel of technology transfer for national diversified firms has been the acquisition or establishment of dedicated biotechnology firms as captive providers of R&D.

One organizational novelty seen in Argentina is that a consortium of pharmaceutical firms has acquired several dedicated biotechnology firms, merged them and converted the resulting company (AMEGA Biotech) into their captive provider of knowledge and biopharmaceutical products. The main shareholder of AMEGA Biotech is Roemmers, one of the largest generic pharmaceutical firms in Argentina (table 3). Box 4 provides more background information on the modes AMEGA Biotech follows to acquire and transfer technology.

Similarly, Bioceres, a group of agricultural associations based in the province of Santa Fe, has also organized a captive provider of biotechnology R&D services: INDEAR. Bioceres is an investment group focused in covering the entire value chain of agricultural biotechnology. Founded in 2001 in Argentina by 23 farmers, it is now owned by 260 shareholders, mostly producers operating

Box 4. AMEGA Biotech: Technology transfer by firm acquisition and industry–academia collaborative networks

The group AMEGA Biotech was established in 2005 as an initiative of the Mega Pharma, a consortium of pharmaceutical firms based in Uruguay.

The group was formed based on the acquisition of three Argentine dedicated biotechnology firms:

- GEMA biotech: an R&D site since 1998
- PC-GEN: a firm incubated by the Institute of Biomedical Research of the Pablo Cassará Foundation and producing IFN alfa, GM-CSF, IL-2 since 1992
- Zelltek: a start-up of the Universidad Nacional del Litoral producing eritropoyetina (EPO) since 1995

Each firm contributed its own R&D and production capabilities, and the founding holding provided the necessary financial resources to develop the research and productive capacities of the new entity.

Following the acquisitions, these firms were restructured to redistribute the activities of R&D, producing active pharmaceutical ingredients, pre-clinical trials, quality control and commercialization.

AMEGA Biotech focuses its activities in the production of biosimilars. The strengths of the group are based on its own R&D capabilities, its know-how of the design and establishment of productive plants (important in the biosimilar market where production processes rather than products are the key competitive advantage) and its collaborative networks.

In terms of collaboration, in January 2013, the National University of Litoral and two subsidiaries of AMEGA Biotech, Zelltek and Gemabiotech, signed a public–private partnership to produce recombinant proteins of high molecular weight not yet produced in Argentina, for which there is a domestic demand.

The project will have a total cost of A$ 37 million ($9.7 million), of which the Government of Argentina will provide 80 per cent and the private firms, the remaining 20 per cent.

The project includes the establishment of a pilot plant, an R&D laboratory for the development of viral controls and a quality control plant. All these plants will be built on lands belonging to CONICET in the province of Santa Fe.

Source: Based on Gutman and Petelski (2010).

in Latin America. INDEAR is the R&D company of Bioceres. It is a venture between Bioceres and the Argentine National Council for Scientific and Technical Research (CONICET), where CONICET contributes with qualified research resources and INDEAR provides funds.

Industry-University-Public research organization collaboration in research and development

In all countries that have adopted biotechnology, one finds a complex structure of collaboration between private firms and academia (Kenney, 1986). Such cooperation is also present in Argentina. Dedicated biotechnology firms, pharmaceutical companies and agricultural associations cooperate with academic researchers and government laboratories. The latter provide knowledge to the former through contracts and consultancy.

Knowledge collaborations (including both R&D and licensing agreements) have largely been conducted with local public research organizations. Cooperation with non-local research organizations (and foreign firms) has also been very relevant. A study of R&D collaboration and innovation performance of Argentine biotechnology firms identifies a strong correlation between firm's innovation output and their engagement in collaborations with local public research organizations and non-local partners (Stubrin, undated).

In Argentina, government policy has supported university–industry research projects. Public funds (through FONTAR) have supported collaborative R&D projects involving bi-directional technology transfer, such as the one that resulted in the discovery of the hydric and saline stress resistant gene (box 5). Public funds have also encouraged joint industry–academia collaboration through

Box 5. University–industry bi-directional technology transfer

In April 2013, the National University of Litoral (UNL) and CONICET, associated with Bioceres, a domestic biotechnology company based in the province of Santa Fe, belonging to a consortium of farmers, announced the successful completion of a nine-year research project supported by FONTAR, Argentina's Technology Fund. The project completed the discovery and isolation of a gene that makes plants resistant to drought and saline soil. The discovery belongs to the Argentine State. It was patented by UNL and CONICET, and licensed to Bioceres, and may result in royalties worth up to $75 million a year to both scientific organizations. The gene will be used in soybeans, maize and sunflower and may result in increases of 20 per cent of the production of these crops and 5 per cent increase in the agricultural production.

Source: Based on www.bioceres. com, USDA (2013).

Box 6. INTI Biotechnology Centre: Collaboration between industry and a public research organization

The Biotechnology Research and Development Centre of the National Institute of Industrial Technology (INTI), formally established in 2009, was set up by INTI and 20 stakeholders, including leading Argentine biotechnological firms (Biogénesis-Bagó, Biosidus, Gemabiotech, Romikin, Biagro, GE Healthcare Life Sciences Argentina, Sartorius Argentina and Millipore/ Biopore) and two academic institutions (CONICET and ANLIS- Malbran) to support the scaling up of bioprocesses in a range of different industries, from pharmaceutical to agriculture.

The Biotechnology R&D Centre addresses two of the main limitations for the development of local biotechnology industries and the use of biotechnology in production processes: the absence of a bioprocessing plant in Argentina and limited industrial biotechnology development.

In 2010, the Centre built a bioprocessing plant with a fermentation scale of up to 50 litres, which is expected to be expanded up to 1000 litres. The financing of such infrastructure has benefited from public financial support (including a FONTAR credit of $2.3 million).

Source: Gutman (2010) and www.inti.gob.ar/biotecnologia.

the financing of R&D infrastructure and equipment in public research organizations, such as the bioprocessing plant installed in INTI's Biotechnology Centre (box 6). AMEGA Biotech is another example of such intense industry–university and public research institution collaboration in R&D (box 4).

Hiring of university graduates by domestic private firms

University–industry technology transfer occurs mostly through the hiring of university graduates by domestic private firms. This is universally acknowledged as the main technology transfer mechanism (Branscomb et al., 1999). Argentine universities and science institutes have provided firms with competent human resources (Gutman and Lavarello, 2011). Most of the professionals working in biotechnology have graduated from local universities, which were among the first in the region to offer biotechnology degrees. It is estimated that around 100 biotechnologists graduate each year.[56] Today, local universities also provide doctoral and postdoctoral training in biotechnology. Argentina has over 64,000 researchers, including 6,230 biologists.[57]

4. 4. Conclusions and policy implications

Argentina is a case of moderate success in the development of biotechnology capabilities. It has been an early adopter of biotechnologies and remains one of the leaders in the region. However, the pace and pattern of technology transfer have not been sufficient to develop endogenous biotechnological capabilities allowing the country to be among the leading emerging biotechnology economies. Economies that started to adopt and invest in biotechnology decades after Argentina, such as the Republic of Korea, Taiwan Province of China and Singapore, are now further ahead.

In the 1980s and 1990s, Argentina was a relatively fast adopter of biotechnology in at least two of its major applications: human and animal health, and agriculture.

In the case of human and animal health, the key adopters were generic pharmaceutical companies, which started producing first- and second-generation biopharmaceutical products such as recombinant insulin, human and animal growth hormones and interferon. The most advanced of them are on the verge of putting biosimilar monoclonal antibodies in the market, as well as heavy molecular weight biologics. The consequences of such developments have been beneficial to Argentina, as the prices of most biopharmaceutical drugs are lower in Argentina than in most countries in the region.

In the area of agriculture, the adoption of biotechnology has been largely the result of the acquisition of genetically modified seeds and other related agricultural inputs from TNCs and has had major economic and social impacts. Agricultural production and productivity have increased, as well as exports and federal revenues derived from production and export taxes. The development of local agricultural biotechnology capabilities is required to reduce dependency on foreign providers, to develop transgenic traits that are particularly relevant for the local agriculture (e.g. drought resistance) and to develop plant varieties more adapted to local tastes and markets.

The development of Argentina's biotechnology sector has largely been due to the availability of qualified human resources and research capabilities and the effort of private business. The main mechanisms for technology transfer have included the following:

- Local academic research, often conducted in collaboration with foreign institutions
- The acquisition of genetically modified seeds and technology from foreign firms
- The flow of FDI in the pharmaceutical industry in the 1990s
- The acquisition and establishment of dedicated biotechnology firms by local firms
- Firm R&D collaboration with local and foreign research organizations
- The hiring of university graduates in private firms

The Government's support for the development of biotechnological capabilities in Argentina

[56] See www.wharton.universia.net/index.cfm?fa=printArticle&ID=2184&language=Spanish.

[57] www.mrecic.gov.ar/userfiles/biotecnologia.pdf́.

has been modest. Argentina's continued policy support for biotechnology and the regulatory framework have facilitated the diffusion of these technologies. However, the development of endogenous biotechnological R&D capabilities has not been a policy priority, in spite of some measures going in that direction. A number of government programmes (including FONCYT, FONTAR and FONARSEC) have, with reduced funds, encouraged collaborative research and intensified university–industry technology transfer. Overall, however, public investment in biotechnology has been limited and the development of biotechnological capabilities by enterprises has largely been the result of private enterprises investment efforts.

The development of the biotechnology industry in Argentina is the result of imitative innovation processes. For example, most domestic pharmaceutical companies are conducting reverse engineering in order to understand the processes through which such drugs were originally produced, or such cloned animals are developed, and produce cheaper versions of biosimilars produced elsewhere. Imitative innovation is often a logical initial stage for firms and countries seeking to acquire new technologies and build technological capabilities. However, such an approach is insufficient to launch products that are new to the international market. Consequently, Argentine pharmaceutical firms today must compete on the basis of price, not on the basis of novelty.

The evolution of the Argentine biotechnology sector offers a number of considerations that are particulary relevant for countries seeking to encourage the transfer of technology and the development of local technological capabilities in the biotechnology sector:

- The local availability of well-prepared human resources and strong research capabilities remains the basic stepping stone for the development of this sector. These are factors that need to be planned for and supported over time.
- A number of context-specific settings (such as, a large agricultural sector) and unintended events (such as the exit of TNCs following a national debt crisis) have provided opportunities for the transfer of technology and the development of local biotechnological capabilities. These factors may not be present in, replicable by, or desirable for other countries. Governments can nonetheless play a strong role in supporting and upgrading the domestic technological capabilities once these or other fortuitous opportunities arise.
- Softer regulatory frameworks have helped spark technology transfer and imitative innovation processes. However, as domestic R&D capabilities develop, such soft regulations may need to be reconsidered to enable local firms compete in countries with more stringent regulations and/or to encourage local investment in R&D.
- Advancing from imitative innovation to the development of products at the technological frontier entails a major leap forward, in terms of availability of highly qualified human resources and R&D infrastructure. It also requires major financial investments, which firms, particularly in contexts of difficult and costly access to finance, will not be able to make. Public support is essential for developing more complex biotechnological capabilities. For instance, public funding will be crucial for upgrading R&D and industrial infrastructure. Measures to facilitate the growth of venture capital markets and other financial mechanisms appropriate for R&D investments will also be required.
- Public policies that encourage the diffusion of biotechnologies are not sufficient to facilitate the upgrading of domestic technological capabilities, unless these are accompanied with solid financial means to develop local R&D and innovation capabilities.
- Intense collaboration networks among private sector and research organizations, both domestically and abroad, have been key to the development of biotechnological know-how and capacity in Argentina. Cooperation has been critical to upgrade and share R&D infrastructure, to make research relevant to industry needs, and to adapt biotechnologies to the local context.
- There is scope for further regional collaboration on R&D efforts to produce transgenic varieties and traits of crops suitable for the local markets and to produce biopharmaceutical drugs.

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Annex 4. Public financing for biotechnology firms in Argentina

Table A4.1 Main funding programmes for research and development that can be used by biotechnology firms in Argentina

Programme	Description	Support	Maximum funding	Other conditions	Amount assigned ($ million)
FONTAR	(Amounts assigned in 2012, are not specifically for biotechnology)				
CRE - CO	Funds aimed at increasing competitiveness of private firms through R&D and modernization projects	National government	Not less than A$ 1 million and up to A$ 5 million	Funds up to 80% of cost of project; 9% annual interest rate.	57.1
ANR*	Funding R&D projects by SMEs, as well as launching R&D laboratories	IADB	Up to 50% of project; reimbursable funds	n.a.	31
ANR Patents	The subsidy allows firms to prepare and present patent applications, local or foreign	National government	Up to $5000 for an Argentine and up to $75,000 for a foreign patent in a BID-member country; supports up to 80% of cost of patent	Permanent programme; beneficiaries are SMEs and universities	
R&D fiscal credit	The subsidy consists in a certificate that can reduce taxes on profits	National government	Up to 50% of the value of project; A$468,750 as maximum credit per firm	Up to one credit per year per firm	13.2
CM	Credits for technical modernization of firms	National government	Up to A$200,000 to be reimbursed 3 years after end of project	Last call for proposals took place in 2006	
CAE - BICE	Credits to companies in order to consolidate technical modernization for projects with high capital goods content	Private and public financial institutions, with government guarantee	Between A$ 1 million and A$ 4 million, up to 80% of project.	Permanent programme	9.4
FONARSEC	(amounts assigned in 2010 specifically for biotechnology)				
FSBIO 2010	Biotechnology sectoral fund. Non-reimbursable fund for projects supporting national production of vaccines and recombinant proteins.	National government	Up to 70% of projects not exceeding A$ 38 million	Non-reimbursable grant of up to A$ 26.6 million). Only for consortiums integrated by at least one firm and one research group. Call made in 2010	17.4
FSBIO 2010 Agrobiotec	Biotechnology sectoral fund. Non-reimbursable fund for projects supporting the development of transgenic varieties for local or adaptable to local conditions; or of vaccines and test kits for endemic animal diseases	National government	Up to 70% of projects not exceeding A$ 38 million	Non-reimbursable grant of up to A$ 26.6 million. Only for consortiums integrated by at least one firm and one research group. Call made in 2010	4.4

Average exchange rate: 2012: A$ 1 = US$0.22; 2010: A$ 1 = 0.257

* ANR is the Spanish acronym for non-reimbursable support (aporte no reembolsable).

Table A4.2 FONTAR: Amounts disbursed by programme, 2012

Instrume	Number of new projects supported	Amounts disbursed (A$ million)	Amounts disbursed ($ million)
CRE+CO	75	259.7	57.1
ANR	375	140.9	31
Tax credit	80	59.8	13.2
ART 2DO credits	86	56.9	12.5
CAE	17	42.9	9.4
All other programmes	37	62.4	13.7
Total	670	622.6	137

Source: ANPCyT (2013).
Average exchange rate 2012 = A$ 1 = US$0.22

Table A4.3 FONTAR: Amounts disbursed by sector, 2012

Sector	Funds disbursed (%)	Amount ($ million)
Machinery manufacturing	15	20.5
Computer software and services	14	19.2
Chemical product manufacturing	9	12.3
Medical and professional instruments	6	8.2
Metal products manufacturing	6	8.2
Food and beverages manufacturing	5	6.8
Electrical machinery manufacturing	5	6.8
All other (includes biotechnology)	40	54.8
Total	100	137

Source: ANPCyT (2013).

Chapter 5. Conclusions

The case studies presented in this report cover a diverse group of industries and economies in the context of differing periods over which these industries were developed. They illustrate that different paths have been taken by policymakers in each case in their approaches to promoting technological upgrading and the development of scientific, engineering, technological and innovation capabilities via technology transfer. These diverging paths reflect variations in policy frameworks for STI, wider development strategies, institutional development and levels of policy intervention, as well as contrasting initial endowments, circumstances and policy priorities. Particularly important among these are the initial levels of technological development of local firms and the availability of local human capital and skills required for the industry in question. The cases reflect the diversity in approaches that are possible and the variety of outcomes that have be achieved in terms of success as measured by technological catch-up and the building of internationally competitive firms and industries. The cases of integrated circuits in Taiwan Province of China and buttons in Qiaotou, China, are both highly successful experiences of technological and industrial upgrading that laid the basis for globally competitive industries. In the cases of biotechnology in Argentina and automobiles in South Africa, the results have been more mixed, with slower technological upgrading and a more nuanced picture in terms of the success of industrial upgrading and international competitiveness.

Differences between industries, national circumstances and policy approaches make every experience in technological upgrading highly specific and unlikely to be broadly replicable. In addition to the complexity presented by diverse experiences, the international economic system continues to evolve, as does the policy environment. Industries such as integrated circuits and automobiles have become more internationally competitive, and are today dominated by large, mostly international firms, often operating through global and regional production networks or value chains. The proliferation of international economic agreements related to trade, investment and wider integration mean that some of the policy tools that were used in earlier periods are no longer available to policymakers. Several lessons can, nevertheless, be drawn from these experiences.

The first lesson is that there are many different paths that are possible to building domestic capabilities and harnessing technology transfer as part of the process. This means that there are no easy formulas to follow, even though inspiration can be drawn from the experiences of others. The lack of any one-size-fits-all blueprint renders the developing country policymaker's job difficult. It may also mean that there is room for policy innovation and diversity in potential approaches, depending upon national circumstances and priorities. Therefore, national policy experimentation and policy learning are likely to be important elements of a successful strategy. So will measurement, monitoring and evaluation of national policies, and policy adjustment over time, in addition to the quality of initial policy design and implementation.

Second, in all of the cases there was active policy intervention to provide incentives and elements of policy support through national and/or sectoral policy frameworks for STI that generally aimed at building human capital and supporting technological upgrading and the development of innovation capacity by local firms and industries. In all cases, there was a need to balance the use of domestic human capital and domestic knowledge generation through R&D with the leveraging of foreign human capital and knowledge, in part through technology transfer. Reliance upon the attraction of TNCs to the domestic economy as a channel of technology and skills transfer without, at a minimum, building adequate local absorptive capacity, is unlikely to lead to successful technological upgrading. All countries that have upgraded technologically in recent decades have invested in building adequate absorptive capacity – human capital, domestic knowledge accumulation and the basic infrastructure needed for R&D. Adequate local absorptive capacity for technological learning by firms and farmers – and policy learning by policymakers – is a prerequisite to technological catching up. In the most successful cases, policymakers have intervened to provide incentives and support to encourage firms and farmers to invest in learning, skills and capability development in order to build the absorptive capacity needed to leverage foreign knowledge and technology. The specific institutional frameworks for managing STI at the national and local levels, the policy frameworks in place, and the actual policy mixes have contrasted significantly. In other words, the goals had some commonality, but the means used to reach them diverged greatly. For countries and firms operating within the technology frontier, which includes most developing countries (and most of their firms), national STI policy action can promote technological upgrading and a process of catching up that narrows the technology gap with more technologically advanced countries and firms. However, our knowledge of what policy mix works best under what circumstances remains at a reasonably early stage of development. This presents a practical challenge in the context of a rapidly evolving international economic environment. It is clear that for a developing country at an early stage of technological development, simply liberalizing the economy and integrating into the global economy without building STI capabilities to support the development of internationally competitive firms and industries, may lead to a reliance upon low wages and low cost production as a means to compete. This approach is unlikely to prove successful as a development strategy in the longer term, especially as wages rise. In the longer term, income growth must be partly driven by raising productivity through technological change and innovation that introduces new or improved products, processes or organisational forms. Innovation must increasingly become a means to compete successfully. In other words, the building of productive capacity that enables structural transformation over the longer term is essential for a successful development strategy.

The third lesson is that technology transfer is an important tool for building national (particularly firm and industry level) capabilities, but this is only a part of the process of developing competitive and innovative firms and industries. The transfer of technology is not equivalent to the transfer of innovation capacity. Innovation capacity is based in part on technological capabilities, but is wider, and requires not only scientific, engineering and technological capabilities. It requires the set of related capabilities needed to transform technical capabilities into successful firms and industries. These capabilities include management, organisational and entrepreneurial capabilities - the ability to integrate available knowledge, technologies and skills, and to recognize and seize potential business opportunities. In order to promote internationally competitive local industry, policymakers must fuse scientific, engineering and technological capabilities to innovation. They must strengthen innovation systems. The goal is to create dynamic capabilities for innovation, which grow over time and respond to changing circumstances. This is better understood today than was the case 40 or 50 years ago. However, how to improve the innovation performance of a firm, industry or country is less well understood. Policymakers in developing countries might start by improving their capacity to identify opportunities for innovation in the economy by building their strategic intelligence capacity. Strategic intelligence capacity is the capacity to provide the type of information needed by actors within the innovation system (in particular the productive sector comprised of firms, farmers and public service providers) in order to enhance their innovation performance. This information will be related to the types of technologies that are available, or will become available, and linking this to the business opportunities in the economy that local firms, farmers and public service providers may be able to exploit. It could also include the identification of successful cases in the economy (or elsewhere) that could be replicated more widely. This type of activity is complementary to efforts to identify areas of economic activity where building comparative advantage may be possible.

The fourth lesson is that policies on technology transfer, or even STI, do not work in isolation to build technological capabilities and accelerate a process of catching up. There are other policy dimensions that also play a key role, including industrial policies, trade, FDI, education and training, intellectual property, SME, entrepreneurship and competition policies. The policy mix is critical, and coherence among policies is important to improve the prospects for successful policy outcomes. The experiences of the most successful catch-up experiences utilized a pragmatic mix of macroeconomic policies with these more structural policies to incentivize and push firms and industries to upgrade technologically. In three of the cases reviewed in this report, FDI or TNCs played some role as a channel for technology transfer, but the mix of complementary policies, and the broader development strategy employed, varied tremendously. However, without education and training policies which build adequate human capital, and STI policies that build R&D infrastructure and capacity, the local linkages and transfer of technology and specialized skills from TNCs that *can* happen may never be realized. Likewise, industrial and trade policies intended to promote industrial development may be undermined by weak innovation systems, skills, capabilities and institutions if STI, and related policy measures, are not implemented to remedy these deficiencies. Similarly, liberalization of trade and investment policies may raise domestic competitive pressures, but weak innovation systems and capabilities may undermine the ability of many local firms to upgrade and innovate in response to a more competitive environment. The systemic nature of innovation means that technology transfer and wider STI policies must be effectively coordinated to improve a country's innovation performance and meet national development objectives. Of course, the design and implementation of effective policies, and ensuring policy coherence, requires a relatively sophisticated policy making capacity, including for policy learning and collaboration. This type of capacity must also be developed.

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