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Ownership and Technological Capabilities: Evidence from Automotive Firms in Brazil, India and South Africa

Rajah Rasiah*
Faculty of Economics and Administration
University of Malaya
Email: rajah@um.edu.my

Abstract: This paper examines the strength of embedding systemic and institutional support, firm-level technological capabilities and the relationship between the two in Brazil, India and South Africa. Despite Brazil and South Africa enjoying stronger exposure to external markets, firms in these countries enjoyed slightly lower technological capabilities than those in India. Stronger human capital endowments and network cohesion have helped firms in India to offset a lack of integration in external markets to drive higher technological capabilities compared to firms in Brazil and South Africa. The systemic pillars are positively correlated with firm-level technological capabilities. Foreign ownership was positively correlated with human resource practices and R&D, demonstrating the potential for strong technological spillovers from foreign to local firms. Export-intensity was positively correlated with R&D, demonstrating that the latter is critical for firms to compete in foreign markets.

Keywords: automotives, Brazil, clusters, India, institutions, South Africa, technology

JEL classifications: L62, O14, O19, O33, O38

1. Introduction

The role of empirical evidence in identifying the key drivers of learning and innovation in firms has arguably been developed most in the works of evolutionary and business economists (see Lall, 1992; Dunning, 1994; Nelson and Winter, 1982; Breschi *et al*., 2000; Cantwell and Mudambi, 2001; Nelson, 2008). Indeed because each industry is different and the nature of latecomer catch up to acquire and develop technological capabilities varies with regions and the time of entry, evolutionary and business expositions often examined particular industrial experiences with an open framework. The focus in this paper is on examining the influence of institutions on the technological capabilities of automotive parts and components firms. The assembly of automobiles was excluded because of significant differences in the nature of competition and scale requirements in that segment in the automotive value chain. The countries chosen for assessment, i.e. Brazil, India and South Africa, are endowed with large domestic markets and have production experience in manufacturing automotives for over half a century. Brazil, South Africa and India had populations of 189.3, 48.3 and 1,151.8 millions each in 2006 (UNICEF, 2008). Despite the huge population differences large domestic markets have been the main springboard for rapid growth in automotive production in all three economies. Aggressive promotion of import-substitution initiated early growth in all three with South Africa being forced to take this route owing to economic sanctions imposed on the country until the replacement of the Apartheid regime in the early 1990s.

This paper seeks to examine the strength of institutions and their relationship with technological capabilities in automotive firms in Brazil, India and South Africa. The rest of the paper is organized as follows. Section 2 discusses the importance and expansion of the automotive industry to Brazil, India and South Africa. Section 3 examines the critical literature on institutions and agglomeration. Section 4 frames the methodology and data used in the paper. Section 5 analyzes the strength of the systemic pillars facing automotive firms in the three countries. Section 6 evaluates the depth of technological capabilities that has evolved in the automotive firms and the significance of export-orientation and foreign ownership controlling for size. Section 7 finishes with the conclusions and policy implications.

2. Importance of the Automotive Industry in Brazil, India and South Africa

American and European firms drove the initial manufacturing of automotives from the early 20th century. Japan and later Korea became latecomer success stories. While the relative market shares of a number of European and American carmakers have declined dramatically the pre-occupation with scale and the levels of sophistication required drove many to believe that automobile assembly will become increasingly concentrated around the leading assemblers' manufacturing locations. Although new start ups in automobile assembly are far fewer than in most other industries automotive parts and component manufacturers have continued to mushroom in both large (e.g. China, India and Brazil) and small (e.g. Malaysia, Thailand and Philippines) economies. Different routes of entry have characterized latecomer assemblers. Heavy protection characterized the initial phase of growth in all latecomer assemblers with joint ventures being the dominant mode of entry in India, while foreign assemblers operated without any pressure to take local equity in Brazil and South Africa. Also, whereas local firms such as Tata and Maruti operated in India, there were no local assemblers in Brazil and South Africa.

Despite the inward-oriented origins, all three countries had become important exporters of automotives in the world by 2006 (see Table 1). The share of automotive exports (including automobiles) in overall national exports was higher from Brazil and South Africa than from India. Despite accounting for a small share of overall national exports, both the absolute volumes and the shares in all three of them rose strongly over the period 2000-2005. Brazil enjoyed the highest export volume in 2006, but exports from South Africa grew the most over the period 1990-2000 at an average annual rate of 21.2 per cent per annum compared to 12.4 per cent from India and 8.7 per cent from Brazil. Exports from India grew the fastest over the period 2000-2006 at 31.1 per cent per annum compared to 19.5 per cent from South Africa and 18.6 per cent from Brazil.

The share of automotive exports in overall national exports has risen gradually (see Table 1). Although the contribution of automotives to overall global exports from the three countries has remained tiny it has risen over the period 2000-2006 (see Table 2). Apart from South Africa where the trade balance was significantly negative, Brazil and India recorded significantly positive figures. The trade balance figure for Brazil worsened in the period 1990-2000 before improving again over the period 2000-2006. India's trade balance figure improved consistently in both periods while that of South Africa worsened over the period 2000-2006.

The sustained expansion of automotive exports obviously raises the need to understand how institutions have related to firm-level technological capabilities in those countries. The key question examined in the paper is whether institutional and systemic support has been important in driving technological capabilities in automotive firms. Given the importance of foreign sources of knowledge in driving technological catch up, the paper also examines the significance of foreign ownership in technological capabilities. Because of the methodology used the assessment is confined to potential technological spillovers from foreign to local firms.

3. A New Model of Clustering: The Systemic Quad

The literature most suitable to constructing a theoretical guide to examine the influence of institutional and systemic elements on firm-level technological capabilities should include works on industrial districts, growth pole, export-processing zones and industrial clustering. Unlike typical Marshallian industrial districts that are dominated by the operations of small firms, automotive-related clusters are characterized by a few large assemblers engaged in completely built up operations. The large assembler is dominant

Table 1: Leading Automotive Exporters, 1990-2006

	1990	2000	2004	2005	2006	2000	2006*
	US$ millions					Percentage*	
World	318959	577113	860287	920408	1015941	9.2	8.6
Argentina	200	2108	2185	3047	4178	8.0	9.0
Australia	726	2151	3088	3525	3267	3.4	2.6
Brazil	2034	4682	8699	11983	13038	8.5	9.5
Canada	28442	60656	63662	66754	66338	21.9	17.1
Chile	18	203	148	178	184	1.1	0.3
China[a]	258	1581	6272	9957	14411	0.6	1.5
EU (25)	–	287190	476986	492031	534044	11.8	11.8
India[b,c]	198	640	1863	2732	3242	1.4	2.6
Indonesia	22	369	875	1340	1724	0.6	1.7
Japan	66195	88082	115733	122903	139161	18.4	21.4
South Korea	2301	15194	32320	37748	43059	8.8	13.2
Malaysia[a]	121	307	554	725	920	0.3	0.6
Mexico[a]	4383	30655	31906	35424	42632	18.4	17.0
Philippines[a]	23	583	1351	1538	1506	1.5	3.2
Romania	354	195	764	1357	2143	1.9	6.6
Russia[c]	–	955	2273	2400	2755	0.9	0.9
South Africa	249	1708	3702	4352	4970	5.7	8.5
Switzerland	591	772	1323	1401	1623	1.0	1.1
Taipei, Chinese	829	2221	3743	3820	3868	1.5	1.8
Thailand	108	2417	5548	7983	9901	3.5	7.6
Turkey[c]	153	1517	8099	9370	11884	5.5	13.9
United States	32547	67195	76417	85993	95344	8.6	9.2

Notes: [a] – includes significant exports from export-processing zones; [b] – figures are for fiscal year; [c] – includes estimates by WTO secretariat; * – of national exports.

Source: WTO (2007: Table 11.54).

Table 2: Trade Ratios, Automotives in Selected Economies, 1990-2006

	1990		2000		2006	
	$(X_i–M_i)/(X_i+M_i)^*$	$X_i/\Sigma X_i(\%)^\#$	$(X_i–M_i)/(X_i+M_i)^*$	$X_i/\Sigma X_i(\%)^\#$	$(X_i–M_i)/(X_i+M_i)^*$	$X_i/\Sigma X_i(\%)^\#$
Brazil	0.585	0.64	0.041	0.81	0.375	1.28
India	-0.137	0.06	0.267	0.11	0.341	0.32
S. Africa	NA	0.08	-0.169	0.30	-0.362	0.49

Note: * – X_i and M_i refer to automotive exports and imports of country i;
\# – refers to percentage share of automotive exports of country X_i in world automotive exports.
Source: Computed from WTO (2007: Table 11.55).

in both the mother-driven Toyota model and the hub and spokes Detroit model (see Guiliani *et al.*, 2005).

Marshall (1890) provided the earliest known elements that constituted a regionally defined set of firms by referring to industrial districts. Young (1928) articulated the advantages industry offers from its differentiating and division of labour potential. In addition to markets and command, Brusco (1982), Sabel and Zeitlin (1997), Piore and Sabel (1982), Becattini (1990), Wilkinson and You (1992), Rasiah (1994) and Pyke and Sengenberger (1992) showed how a systemic framework with a blend of influence from markets, government and trust-loyalty (social capital) have been instrumental in driving productive networks of industrial synergies.[1] Piore and Sabel (1982), Hirst and Zeitlin (1991) and Sengenberger *et al.* (1990) offered a dynamic and coherent account of inter- and intra-firm coordination of horizontally evolving relationships that promise the impetus for the transition to a high road to industrialization.

There has also been an interesting development of the theory of agglomeration economies with a focus on growth poles and lead sectors. Theories of state power and regional organizations have focused on the role development organizations play in stimulating industrial activities by concentrating infrastructure in particular locations. Early work from geographers and development economists examined the advantages of developing growth-pole strategies (see Perroux, 1950, 1970; Boudeville, 1966; Hirschman, 1958, 1970; Myrdal, 1957) on regional development. Unlike the concept of clusters which examines regional dynamics as a network of economic agents, growth pole was referred to by Perroux (1950) as an industry or a group of firms that drove the growth of other firms and economic activities most in the region: polarization arising from the propulsive development of a firm or industry. The synergy effects of agglomeration economies have been documented lucidly subsequently by Cooke and Morgan (1998), Garofoli (1992), Porter (2001), Scott (1988) and Storper (1995). Hirschman (1958, 1970) canvassed strongly for export-orientation to attract the discipline and scale effects of markets to promote competition and backward linkages to raise economic synergies from growth in the lead sectors.

Export processing zones (EPZs) became important from the 1950s when the United Nations Conference for Trade and Development (UNCTAD) and the United Nations Industrial Development Organization (UNIDO) initially promoted these institutions in poor economies unable to provide good infrastructure, industrial support and security throughout each country. The initial absorption of the views of Perroux, Hirschman and Mydral on lead sector drivers in industrial estates was quickly replaced by the World Bank approach of limiting export-processing zones to simply the provision of basic infrastructure, smooth customs coordination and security. It is the latter hands-off approach that has proliferated across developing economies subsequently. The initial success from foreign direct investment (FDI) inflows that helped create jobs by targeting production to export markets proved successful even in small economies such as Malaysia, Ireland and Singapore, albeit trade leakage became a problem in some countries. However, countries that simply continued this liberal approach gradually began to lose FDI inflows as production costs rose and cheaper sites emerged. Singapore and Ireland took on an interventionist approach to stimulate upgrading and value addition to off-set rising production costs.

It is the failure of industrial estates (including EPZs) to engender upgrading and hence long-term growth that drove several countries to experiment with industrial clustering. The focus of Porter (2001) has been on the agglomeration effects of clusters led by a critical mass of firms specializing in a key competency but driven by a particular industry, while Best (2001) emphasized the productivity triad – business model, human capital supply and production capability spectrum – to drive differentiation and division of labour. Both approaches explain how mature networked regions stimulate economic synergies, but lack focus on how underdeveloped regions can be transformed to such regions. Those approaches do not identify exhaustively the critical pillars that drive successful clustering. They tend to obfuscate the boundaries between firm-level strategies and government policy. Hence, Rasiah's (2007) systemic quad is used in this paper to examine institutional support and its impact on technological capabilities in a sample of automotive firms in Brazil, India and South Africa.

Clusters in this paper are defined as a regional or local network of economic agents (firms and institutions) that enjoy at least some level of connectivity between them. In dynamic clusters the links between the economic agents are not only strong, but also horizontal with the critical institutions in place to drive learning, innovation and competitiveness. Clusters are considered to produce the most synergies when all the requisite institutions to drive learning, innovation and competitiveness are developed with strong connectivity and coordination between them to drive innovation and competitiveness through circular and cumulative causal processes. What Young (1928), Abramowitz (1956), Kaldor (1957, 1977) and Cripps and Tarling (1973) argued at an abstract and aggregate level can be presented in network terms through the concept of clusters.

Governments can create or strengthen the institutions to promote agglomeration effects. Government can also screen particular clusters and identify bottlenecks, gaps and weaknesses to ease, fill and ameliorate these problems. Such problems can take the form of critical basic infrastructure, high tech infrastructure, or supplier firms. Given the problems of information asymmetries between government and firms, intermediary organizations such as chambers of commerce, training institutions and R&D labs often help resolve collective action problems. Interdependent relationships that are driven by the discipline of the market, participation of government when public goods are involved and complementation through trust-loyalty to extract social commitment from the humans directing all of them, are vital for the development of competitive clusters. Stakeholder coordination (e.g. through industry, government, consumer and labour coordination councils) often help root and expand social capital.

A lack of firm-level drive, of human capital and high tech institutions necessary to stimulate innovation and competitiveness have often undermined the capacity of clusters to enjoy sustainable differentiation and division of labour, which are also the prime reasons for the stagnation that has characterized industrial estates in many developing economies. Attempts to initiate catch up strategies should start with the mapping of firms, institutions, policy framework and their integration with markets (global and local), and to identify the existing and potential drivers of industrial dynamism in particular regions or locations.

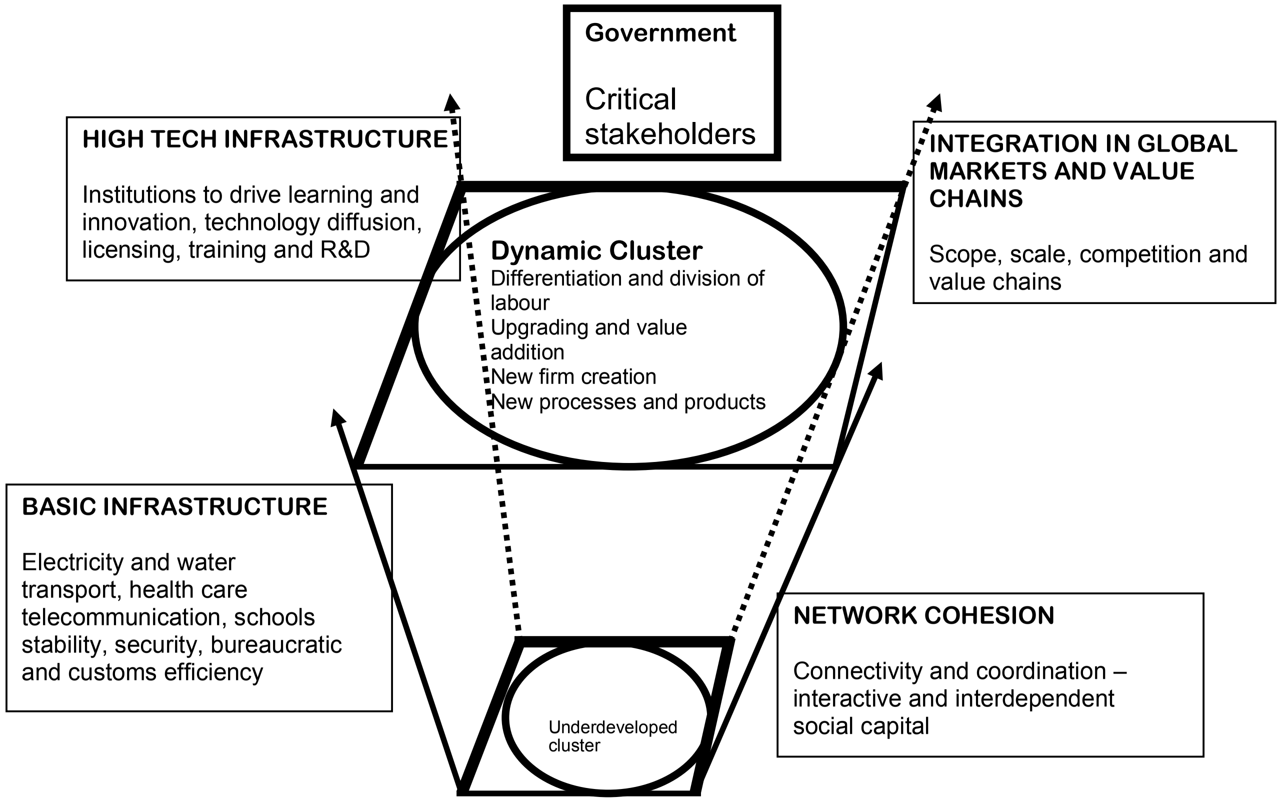
Frontier clusters (high tech clusters in Porter's notion and any dynamic cluster in Best's definition) are characterized by innovation. The focal point of innovation in a dynamic cluster is essentially the interdependent and interactive flow of knowledge and information among people, enterprises and institutions, which must include 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. In dynamic clusters such as the Silicon Valley and Route 128, innovations evolve from a complex set of inter-relationships among actors located in a range of enterprises, universities and research institutes. The execution and appropriation of these innovations *inter alia* expand further actors in dynamic clusters to intermediary organizations such as suppliers, venture capitalists, property rights lawyers and marketing specialists. The United States' government continues to fund strategic research in the military, universities and other laboratories (NSF, 2003).

Figure 1 identifies the four critical pillars that drive dynamic clustering. The first pillar of a dynamic cluster is basic infrastructure and the provision of stability (macroeconomic, political and security). The second is high tech infrastructure, which is critical to stimulate learning and innovation. High tech institutions are important to stimulate learning by doing, licensing, adaptation, training, standards appraisal, a strong intellectual property right framework to prevent free rider problems facing innovators and R&D.

The third refers to institutions that provide network cohesion and integration. Lundvall (1988, 1992) expanded the elements of interdependence and interactiveness by articulating the role of producer-user relations in innovation. The nature of interface and coordination between economic agents is vital in the horizontal evolution of innovation activities. Connectivity and coordination is critical for knowledge flows – beyond simply codified information that markets can coordinate. Intermediary organizations such as industry-government coordination councils and chambers of commerce play an important role to increase connectivity and coordination in dynamic clusters. In emerging regions, governments have initiated such efforts (e.g. Penang in Malaysia) (see Rasiah, 2002). The appropriation of knowledge through rubbing off effects increases as humans employed by firms and organizations in clusters meet and interact, and the frequency of movement of tacit knowledge embodied in humans to start new firms, rises. The role of trust and loyalty (social capital) is also vital as a coordination mode (see Rasiah, 1994).

The fourth requires that the cluster is globally connected – markets and value chains. Global markets provide the economies of scale and scope and the competitive pressure to innovate. Global value chains assist economic agents in the cluster to orientate their strategies to the critical dynamics that determine upgrading and value addition (see Gereffi, 2002; Gereffi *et al.*, 2005). Examples of such changes include the introduction of cutting edge just in time and flexible specialization techniques in electronics, the proliferation of software technology in the use of cad-cam machines and the interface between firms' assembly activities and the major markets abroad. In Indonesia for example, Texmaco which is located in Karawang in the outskirts of Jakarta responded to the changing nature of global value chains in the garment industry by integrating assembly, fashion design, packaging and logistics to supply brand-name holders. Despite lacking in institutional support – both basic and high tech infrastructure – Texmaco has managed to compete globally.

Figure 1: Systemic Quad



Source: Rasiah (2007)

Economies that managed to strengthen the four pillars of the systemic quad have managed to sustain several decades of rapid growth and employment absorption, value addition and exports (e.g. Singapore, Taiwan, Hong Kong, Ireland and Israel). Economies that focused only on providing basic infrastructure in industrial estates have failed to sustain growth and employment absorption, value addition, sustained exports (Lall, 2001). Whereas sustained value addition, differentiation and division of labour, and wage increase have helped raise standards of human development sharply in the successful economies, the lack of such factors has denied this experience in the unsuccessful economies.

4. Methodology and Data

Recognizing that technological spillovers are often non-pecuniary in nature and fall outside market-based transactions (see Marshall, 1890; Scitovsky, 1964; Rosenstein-Rodan, 1984), Rasiah (1994, 1995) used electronics component and textile multinationals and a snowballing methodology of tracing production and technological linkages to examine technological capabilities directly to explain technical change and competitiveness. Lall (1992) provided the first typology of technological capabilities by taxonomies and trajectories. Lall (2001) had argued first, for the need for connecting firm-level capabilities with macro-policies because learning and innovation are not costless and second, that firms make conscious efforts to move to the technology frontier. Rasiah (2004, 2006, 2007) pursued Lall's (2001) and Katz's (2006) calls to connect the micro with the macro by establishing empirical evidence of a strong positive relationship between firm-level technological capabilities and strategies with the macro-level systemic and institutional capabilities and policies.

Table 3: Variables, Proxies and Measurement Formulas, Automotive Firms

Variable	Proxies	Specification
Human Resource	Training expenditure in payroll, HR practices and skill-intensity	Normalized using formula: $(x_i - x_{min})/(x_{max} - x_{min})$
Process Technology	Age of machinery and equipment, inventory and quality control systems, expenditure on inventory and quality control systems, process patent	Normalized using formula: $(x_i - x_{min})/(x_{max} - x_{min})$
Product Technology	R&D expenditure in sales and R&D personnel in workforce	Normalized using formula: $(x_i - x_{min})/(x_{max} - x_{min})$

Source: Developed by author.

Table 4: Taxonomy and Trajectory of Automotive Firms

Knowledge depth	Human resource	Process	Product
Simple activities (1)	On the job and in-house training	Dated machinery with simple inventory control techniques	Assembly or processing of component, CKD and CBU using foreign technology
Minor improvements (2)	In-house training and performance rewards	Advanced machinery, layouts and problem solving	Precision engineering
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 OEM capability
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, ODM
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, OBM

Note: CKD – completely knocked down; CBU – completely built up; TQM – total quality management; TPM – total preventive maintenance; QCC – quality control circle; TQC – total quality control; OEM – original equipment manufacturing; ODM – original design manufacturing; OBM – original brand manufacturing.

Source: Developed from Lall (1992), Rasiah (1994, 2007) and Figueiredo (2002, 2003).

This paper thus examines firm-level technological capabilities and the relationship between them and the embedding institutional and systemic capabilities. The paper uses comparisons of simple means to examine differences in firms' assessment of institutional and systemic instruments facing them, as well as in technology of foreign and local firms in Brazil, India and South Africa. Likert scale scores ranging from 0-5 were used to score firms' rating of connections and coordination quality with critical institutions. The estimation of the technological capability variables is shown in Table 3. Table 4 differentiates the technological capability variables by taxonomy and trajectory (see Dosi, 1982; Pavitt, 1984). The technological capability framework first pioneered by Lall (1992) and later developed further by Figueiredo (2002, 2003) and Rasiah (1994, 1995, 2007) is used to estimate the firm-level incidence of knowledge capability.

The data used in this paper is drawn from surveys coordinated by the author in 2003-2004 on a broader set of industries. Information on the automotive firms in Brazil, India and South Africa was extracted from this survey. The national consultants who collected the data used a sampling frame supplied by state authorities taking account of size and ownership. The data obtained is shown in Table 5. Unless otherwise stated all information presented is for the year 2002.

4.1 Specification of Dependent Variables

Three technological capability variables are used as dependent variables in this paper, viz., human resource, process technology and R&D. Firm-level technologies include human resource practices, machinery and equipment, inventory and quality control systems and R&D expenditure and personnel. Because there are no prior reasons to attach greater significance to any of the

Table 5: Breakdown of Sampled Data, Automotive Firms, 2002

	Brazil		India		South Africa	
	CKD	Component	CKD	Component	CKD	Component
Mailed	50	30	50	30	50	30
Responses	21	13	33	17	38	17
Interviewed	2	2	5	4	3	6

Note: CKD – completely knocked down.
Source: Computed from UNU-MERIT (2003-2004) survey.

proxies used, the normalization procedure used is not weighted. The following technological intensities are specified:

Human Resource

Human resource (HR) capability was estimated as follows:

$$HR_i = 1/3[TE_i, CHRP_i, SI_i]$$

TE, CHRP and SI refer to training expense as a share of payroll, cutting edge HR practices (estimation formula: a score of one was added to any one of the cutting practices of small group activities, team-working, quality control circles, stock sharing and performance-based rewards and promotions), and skill-intensity (estimation formula: professionals, technicians, machinists and skilled workers divided by total workforce) of firm i (see Table 3). Because the proxies were evenly weighted HR was divided by 3 to take account of the three proxies used.

Process Technology

Process technology (PT) capability was estimated as follows:

$$PT_i = 1/3[PTE_i, IQCS_i, K/L_i]$$

PTE, IQCS and K/L refer to process technology expenditure in sales, cutting edge inventory and quality control systems (estimation formula: a score of one was added to any one of the cutting practices of just in time, quality standards (QS) or ISO 9000 series, statistical process control, total quality management, defect tolerance rate by parts per million and total preventive maintenance), and capital intensity (fixed capital divided by workforce) of firm i respectively (see Table 3). Because the proxies were evenly weighted PTE was divided by 3 to take account of the number of proxies used.

R&D Capability

R&D (RD) intensity was measured as follows:

$$RD_i = 1/2[RDexp_i, RDemp_i]$$

where RDexp and RDemp refer to R&D expenditure in sales and R&D personnel respectively of firm i (see Table 3). Because the proxies were evenly weighted, RD was divided by 2.

4.2 Specification of Independent Variables

The paper uses standard correlation analysis for establishing statistical significance of the means of the institutional and systemic variables – i.e. basic infrastructure (BI), high tech infrastructure (HI), network cohesion (NC) and global integration (GI) – and the technological capability variables HR, PT and RD, as well as cross-sectional regressions, to examine the relationship between the first set of variables and the second set of variables controlling for other variables. Circular causation is assumed in the paper following the arguments of Young (1928), Kaldor (1957) and Cripps and Tarling (1973). The independent variables used in the paper are specified below and their expected relationships with technological capabilities are shown in Table 6.

Systemic Quad

The systemic quad (SQ) series of data takes account of all the four systemic pillars, i.e. BI, HI, NC and GI. SQ is measured as follows:

$$SQ_i = 1/4(BI_i + HI_i + NC_i + GI_i)$$

The technology components of HR, PT and RD are expected to be positively correlated with SQ. Because the firms surveyed are from the same locations (Sao Paolo in Brazil, Delhi in India and Johannesburg in South Africa) the variance in systemic support facing the firms in each of the countries is not expected to be high and hence, the statistical analysis is pooled to include all the three countries. The use of SQ can have both positive and negative implications. On the positive side it helps draw firms' assessments of connections and coordination with the relevant institutions for estimating institutional and systemic support, including explaining the geographical dispersion in institutional support across individual location regions or locations. On the negative side it could introduce perceptive biases. The national consultants who faced the officials of all the responding firms were strictly asked to rate their assessment on the basis of what they think should be the worst (0) and best (5).

Export-intensity

Export markets are viewed as a driver of efficiency improvements providing the scale for backward linkages (Hirschman, 1970). Export-intensity is measured as:

$$\text{Export intensity} = X_i/Y_i$$

where X and Y refer to export and gross output respectively of firm i in 2002. X/Y is expected to show a positive relationship with the technology variables, but this may not occur because of the heavy inward-orientation of automotive parts and component firms in these countries (see Table 6).

Ownership

Although the evidence on the influence of foreign ownership on technological capabilities is mixed (see Amsden *et al.*, 2001; Lall, 1992; Rasiah, 1994; Dunning, 1994; Cantwell, 1995; Cantwell and Mudambi, 2001; Ernst, 2006), the long assembly experience, presence of strong intensity of R&D scientists and engineers and large domestic markets is likely to have attracted designing activities to meet domestic and regional demand. Also, interviews show that multinational corporations have attempted to develop regional models as part of their corporate strategy to compete better in regional markets (see also Quadros and Queiroz, 2001). Hence, a positive relationship is expected between technological capabilities and foreign ownership (FO) (see Table 6). FO is estimated as follows:

FO_i = Foreign equity/total equity

Size

There is a long standing debate on the importance of size in relation to firms' competitive and technology levels. Typical industrial organization arguments posit that firms achieve competitiveness with a certain minimum efficiency scale (MES), which varies with industries (see Scherer, 1980, 1992; Pratten, 1971). Automotive parts and components firms are diverse in that some sub-sectors are scale-intensive (e.g. shock absorbers, exhaust pipes and stereo sets) while some specialize on the basis of scope (e.g. command navigation systems, contract R&D and robotics). Where scale is unimportant – e.g. small-batch components – scope rather than scale is important (Piore and Sabel, 1982; Rasiah, 1994). Audretsch (2002) offered persuasive analysis of US data to dispel arguments related to the significance of large size in efficiency and innovative activities. Hence a neutral hypothesis is assumed between technological capabilities and size. Size (S) was measured as:

S_i = actual employment of firm i in 2002

where S refers to size of firm i.

The control variable of age was tested and dropped because of problems of multi-correlinearity with size and country dummies (see Appendix 1).

Table 6: Expected Relationship between Technological Capability and Independent Variables, 2002

	HR	PT	RD
SQ	+ve	+ve	+ve
X/Y	+ve	+ve	+ve
FO	+ve	+ve	+ve
S	Unclear	Unclear	Unclear

Source: Computed from UNU-MERIT (2003-2004) survey.

4.3 Specification of Statistical Equations

The following equations are then estimated to examine the statistical relationship between the technological capability variables and the explanatory variables of systemic quad, export-intensities, foreign ownership and size controlling for country dummies. Age was dropped because of multicollinearity problems with size.

$$HR = \alpha + \beta_1 SQ + \beta_2 FO + \beta_3 X/Y + \beta_4 S + \mu \quad (1)$$

$$PT = \alpha + \beta_1 SQ + \beta_2 FO + \beta_3 X/Y + \beta_4 S + \mu \quad (2)$$

$$RD = \alpha + \beta_1 SQ + \beta_2 FO + \beta_3 X/Y + \beta_4 S + \mu \quad (3)$$

Because the variables HR, PT and RD are censored on both the left and right with a minimum value of 0 and a maximum value of 1, Tobit regressions were preferred over OLS regressions (see Greene, 1981).

5. Systemic Pillars

This section uses the systemic quad to examine the strength of the systemic pillars facing automotive firms in Brazil, India and South Africa. The purpose of this exercise is to establish firms' assessment of the critical pillars necessary to support the upgrading of firm-level technological capabilities.

5.1 Basic Infrastructure

The means of Likert scale ratings ranging from 0 (weakest) to 5 (strongest) of basic infrastructure by automotive firms in the three countries are shown in Table 7. Overall, firms in South Africa (3.21) provided the highest rating of the strength of basic infrastructure among the three countries with Brazil (2.81) and India (2.82) enjoying similar means.

The statistically significant means were above average in all three countries for transport, power and telecommunications and below average for healthcare and government coordination efforts. Firms' mean rating of water supply was below average in India. Firms rated the availability of finance below average in Brazil. Indeed interest rates facing firms in Brazil in 2002 often reached 20 per cent with the government providing no subsidized credit. Firms also rated schooling (primary and secondary) below average in Brazil and South Africa.

It appears that the provision of power (especially electricity) in industrial estates is adequate in the three locations with South Africa (3.69) and Brazil (3.32) enjoying the highest ratings. Interviews show that power supply in general is good in Brazil and South Africa but not in India. Government policy

Table 7: Basic Infrastructure, Automotive Firms, Brazil, India and South Africa, 2002

	Brazil	India	South Africa
Transport	2.85 (0.09)*	3.30 (0.07)*	3.95 (0.11)*
Power	3.32 (0.19)*	2.70 (0.09)*	3.69 (0.07)*
Water	3.97 (0.14)*	2.38 (0.07)*	3.88 (0.10)*
Telecommunications	3.76 (0.13)*	3.12 (0.07)	3.69 (0.09)*
Healthcare	2.09 (0.09)*	2.34 (0.07)*	2.25 (0.07)*
Government Licensing Customs Security	2.03 (0.13)*	2.40 (0.08)*	2.01 (0.07)*
Finance	2.24 (0.18)*	3.54 (0.08)*	3.01 (0.11)*
Primary and Secondary Schools	2.21 (0.09)*	2.76 (0.07)*	2.45 (0.09)*
Basic Infrastructure	2.81 (0.05)*	2.82 (0.04)*	3.21 (0.05)*

Note: Figures in parentheses refer to standard errors; * – significant at 1% level.

Source: Computed from UNU-MERIT (2003-2004) survey.

was reported as important in ensuring adequate power supply to automotive firms in industrial estates.

Healthcare and government services were rated poorly in all three countries. Where the firms are located there is a trend towards seeking private healthcare owing to poorly equipped government hospitals. Interestingly the pharmaceutical industry is fairly developed in all three countries. The three components of government services had wide variation with licensing and customs services rated above average while security fell below 2.00 in Brazil and South Africa. India's scores hovered between 2.31 and 2.59 for all three components. Security facing employees was reported as a very serious problem in South Africa.

5.2 High Tech Infrastructure

The means of Likert scale ratings ranging from 0 (weakest) to 5 (strongest) of high tech infrastructure by automotive firms in the three countries are shown in Table 8. Overall the mean rating of high tech infrastructure in the three were similar with Brazil (2.76) enjoying a marginally higher mean than India (2.73) and South Africa (2.73).

Table 8: High Tech Infrastructure, Automotive Firms, Brazil, India and South Africa, 2002

	Brazil	India	South Africa
Technical Training	2.79 (0.14)*	3.06 (0.08)*	2.87 (0.15)*
University	3.18 (0.12)*	3.36 (0.07)*	3.20 (0.17)*
R&D Scientists and Engineers	3.02 (0.17)*	3.26 (0.09)*	2.99 (0.20)*
R&D Incentives and grants	2.30 (0.19)*	2.42 (0.07)*	2.01 (0.27)*
R&D labs	2.47 (0.19)*	2.20 (0.06)*	2.02 (0.14)*
Standards Organizations	2.53 (0.19)*	2.16 (0.07)*	3.27 (0.17)*
High Tech Infrastructure	2.76 (0.13)*	2.73 (0.04)*	2.73 (0.09)*

Note: Figures in parentheses refer to standard errors; * – significant at 1% level.

Source: Computed from UNU-MERIT (2003-2004) survey.

The provision of technical training, university education and R&D scientists and engineers were rated above average, while R&D incentives and grants along with R&D labs were below average in all three countries. Indeed, interviews showed that both government technical training and university education were advanced in India while private operators often substituted strongly those who could afford them in Brazil and South Africa. The internalization of R&D activity in firms is largely the prime source of R&D operations in automotive firms in all three countries, though firms also relied extensively on contract R&D activities in Brazil.

Standards organizations were rated highest in South Africa (3.27) among the three countries. Standards organizations in South Africa not only participate in evaluating and supporting firms' operations in South Africa, but also abroad. The main source of quality control improvements in automotive firms in Brazil and India in 2002 appeared to come from their component and parts buyers as well as machinery and equipment suppliers.

5.3 Network Cohesion

The means of Likert scale ratings ranging from 0 (weakest) to 5 (strongest) of network cohesion (connectivity and coordination) by automotive firms in the three countries are shown in Table 8. Overall the mean rating of network cohesion in the three clusters was significantly higher than average with firms in India (3.77) enjoying an edge over firms in South Africa (3.47) and Brazil (3.26). Interviews suggest that the high levels of connectivity and coordination in the three countries arose as a consequence of strong relationships between buyers, suppliers and distributors (see Table 9).

Apart from R&D support in India, strategic partners in Brazil and the role of government in South Africa, all organizations enjoyed above average connections with automotive firms in the three countries (see Table 8). Interviews show that excessive procedures were a major problem in firms' efforts to seek R&D assistance in India. Strategic partnerships have not performed well in Brazil owing to imports of cheaper components (largely caused by a crash in the peso) from Argentina under the Mercusor Agreement (Bernat, 2008). Problems of security were reported as the only reason why automotive firms in South Africa rated the role of government below average.

Automotive firms have developed their own software systems and hardware adaptations using the wide pool of human capital available in India. The higher levels of networking between firms and institutions (especially training institutes and universities) in India compared to Brazil and South Africa is reported to have evolved into curriculum development that is strongly tailored to meeting firms' demands.

Table 9: Network Cohesion, Automotive Firms, Brazil, India and South Africa, 2002

	Brazil	India	South Africa
R&D	2.74 (0.25)*	2.28 (0.08)*	2.63 (0.21)*
Finance	3.50 (0.11)*	4.52 (0.07)*	3.69 (0.12)*
Distribution	3.26 (0.26)*	4.44 (0.08)*	3.87 (0.17)*
Suppliers	3.71 (0.17)*	3.84 (0.07)*	3.81 (0.14)*
Buyers	4.09 (0.14)*	4.76 (0.07)*	4.03 (0.06)*
Standards Organization	3.29 (0.16)*	3.60 (0.07)*	3.91 (0.11)*
Government bodies	3.21 (0.17)*	3.69 (0.11)*	2.15 (0.09)*
Industry Association	3.24 (0.17)*	2.88 (0.08)*	3.25 (0.07)*
Strategic partners	2.35 (0.21)*	4.00 (0.09)*	3.87 (0.12)*
Network Cohesion	3.26 (0.15)*	3.77 (0.04)*	3.47 (0.11)*

Note: Figures in parentheses refer to standard errors; * – significant at 1% level.
Source: Computed from UNU-MERIT (2003-2004) survey.

5.4 Global Integration

Owing to paucity of data, only exposure to export and import markets from abroad were used to estimate global integration index here. The data did not include information on the extent of licensing, intra-multinational flows of knowledge and in-migration of human capital from abroad. Although the share of exposure to developed markets will be the best to examine the effects of technology inflow from developed economies the questionnaire used for South Africa did not include questions on imports from developed markets.

Brazil appeared the most integrated in global markets followed by South Africa with India showing very low integration levels (see Table 10). Both export and import shares in output of automotive firms in Brazil exceeded that of firms in India and South Africa. Interviews show that most imports involved automotive components and parts, and machinery and equipment. The share was highest in Brazil owing to multinational buyers imposing high quality conditions on suppliers. Indeed, rising demand for high quality and precision has driven the rationalization of the automotive industry in Brazil and South Africa.

Brazil and South Africa appear to be the biggest beneficiaries of global integration among the three countries in the automotive parts and components industry as they not only enjoy more foreign exchange earnings from exports but also the diffusion of technology embodied in machinery and equipment, components and parts. Indian firms have relied more on domestic institutions among the three countries.

Although greater competition from higher exposure to global markets is expected to force greater efficiency improvements in Brazil and South Africa, India's larger domestic market with increasing entry of foreign assemblers is expected to provide some substitution effect. The overall indices of basic infrastructure, high tech infrastructure and network cohesion in all three locations are similar. Besides, scale is less important in component and parts manufacturing compared to automobile assembly. With the exception of skill intensity because of higher endowments of technical training institutes and stronger networking between firms and training and university institutions in India compared to Brazil and South Africa, differences in endowments and structural conditions are not expected to produce large differences among technological capabilities in automotive firms in the three countries.

Table 10: Extent of Global Integration, Brazil, India and South Africa, 2002

	Brazil	India	South Africa
X/Y (%)	39.7 (6.0)*	5.8 (1.4)*	14.5 (1.8)*
M/Y (%)	78.9 (3.4)*	17.4 (2.1)*	40.4 (3.9)*
GI (%)	118.6 (8.5)*	23.2 (2.9)*	55.0 (5.7)*

Note: Figures in parentheses refer to standard errors; * – significant at 1% level.

Source: Computed from UNU-MERIT (2003-2004) survey.

6. Technological Capabilities

This section analyzes the technological capabilities enjoyed by automotive firms in Brazil, India and South Africa. Although the overall ratings of the systemic pillars have been similar the mean scores of technological capabilities of automotive firms in all three economies may produce different results because of the significantly higher human capital endowments and stronger networking between firms and institutions in India than in Brazil and South Africa. Firms in Brazil and South Africa enjoy higher integration in global trade markets than firms in India.

6.1 Comparison of Technological Capabilities

Using descriptive statistics this section compares the strength of the technological capabilities of human resource, process technology and R&D of automotive parts and components firms in Brazil, India and South Africa.

Human Resources

Firms in India (0.63) enjoyed higher human resource (HR) capabilities than firms in Brazil (0.52) and South Africa (0.52) (see Table 11). The much higher skill-intensity (SI) of firms in India (85.6%) compared to those in Brazil (64.8%) and South Africa (52.3%) contributed to this difference. Firm-level interviews show that the strong supply of technical graduates – from certificates until first degrees – has made their hiring easy and less costly in India compared to Brazil and South Africa.

Firms in Brazil (9.4%) showed a higher training expenditure in sales (TE) mean than firms in India (4.5%) and South Africa (4.5%). However, the supply of skilled technical personnel below engineers is low in both Brazil and South Africa. Interviews suggest that firms in Brazil compensate for lower entry point qualifications than firms in India with training. High labour turnovers seem to have discouraged somewhat emphasis on a similar approach in South Africa. Auto-controlled systems that rely on the strong use of process engineers has helped reduce the reliance of skilled machinists and technicians. Although Brazil and South Africa are more integrated with external markets than India as can be seen from the export and import intensities and GI index shown in Table 11, this has not translated significantly into the utilization of superior human resource practices.

Process Technology

Firms in India (0.57) again enjoyed a marginally higher process technology (PT) mean than firms in South Africa (0.55) and Brazil (0.43) (see Table 11).

Whereas firms in India enjoyed a much higher mean in the incidence of use of cutting edge inventory and quality control systems (IQCS) and process technology expenditure in sales (PTE) than firms in Brazil and South Africa, it was the opposite in the age of machinery used.

Interestingly the lack of exposure to export and import markets has had little bearing on the deployment of cutting edge IQCS and process technology

Table 11: Technological Capabilities, Automotive Firms, Brazil, India and South Africa, 2002

	Brazil	India	South Africa
TE (%)	9.4	4.53	4.47
	(3.80)**	(0.26)*	(0.30)*
CHR	0.93	0.89	0.91
	(0.02)*	(0.01)*	(0.02)*
SI (%)	64.80	85.58	52.27
	(5.00)*	(0.84)*	(2.56)*
HR	0.52	0.63	0.52
	(0.03)*	(0.01)*	(0.03)*
IQCS	0.52	0.73	0.56
	(0.05)*	(0.02)*	(0.02)*
PTE (%)	2.92	5.60	6.21
	(0.52)*	(0.29)*	(0.51)*
MA	4.26	4.02	4.25
	(0.15)*	(0.03)*	(0.12)*
PT	0.43	0.57	0.55
	(0.04)*	(0.02)*	(0.04)*
RDE (%)	2.81	1.30	1.04
	(0.05)*	(0.06)*	(0.06)*
RDP (%)	2.56	9.95	7.98
	(0.03)*	(0.63)*	(0.52)*
Patents (US)	0.15	0.18	2.59
	(0.06)*	(0.08)*	(0.20)*
RD	0.19	0.29	0.23
	(0.03)*	(0.02)*	(0.01)*

Note: Figures in parentheses refer to standard errors; * and ** – significant at 1% and 5% level respectively.

Source: Computed from UNU-MERIT (2003-2004) survey.

expenditure incurred by firms in India. Interviews show that most firms have both directly deployed best practices to meet demands imposed by buyers (including foreign assemblers producing for the domestic market) and accessed codified knowledge from business and engineering magazines. Also, firms in India use their higher intensity of engineers, technicians and machinists to continuously modify and upgrade old machinery. The age of machinery and equipment (MA) on average was newer in firms in Brazil (4.26) and South Africa (4.25) than in firms in India (4.02), though the margin was not large.

R&D

The proxies of R&D expenditure in sales and R&D personnel in workforce were used to estimate RD. Patent take up in the US was dropped because firms in India and Brazil preferred to take up patents within the country owing to the greater relevance of their use in domestic markets. Firms in India (0.29) enjoyed a higher R&D capability than firms in South Africa (0.23) and Brazil (0.19) (see Table 11).

Firms in Brazil (2.8%) showed the highest intensity of R&D expenditure (RDE) in sales compared to India (1.3%) and South Africa (1.0%). The provision of special grants and financial incentives for firms seeking R&D activities as well as approval conditions to utilize R&D support from domestic institutions in developed states such as Sau Paolo may explain this wide difference between firms in Brazil compared to those in India and South Africa. Firms in India (10.0%) showed the highest intensity of R&D personnel in the workforce exceeding those of South Africa (8.0%) and Brazil (2.6%). Interviews show that firms in India and South Africa relied significantly on their own personnel to carry out R&D activities while firms in Brazil in addition also relied extensively on contract R&D with government labs and universities.

The mean take up score of patents in the United States by South African firms was 2.6 per firm compared to only 0.2 patents per firm in India and Brazil, which is all the more interesting given that these figures are statistically significant at the 1 per cent level. Interviews show that South Africa's main target of output is also domestic markets, but the failure of their intellectual property rights (IPR) regime as well as exports to the United States and Europe drove firms to apply for patents in the United States.

Overall, automotive firms in India showed a slightly higher HR, PT and RD mean than firms in Brazil and South Africa suggesting that exposure to international markets has not made significant differences in the development of technological capabilities. Indeed foreign equity ownership was also lowest among Indian firms compared to firms in Brazil and South Africa.

Knowledge Depth

Table 12 shows the incidence of participation of automotive firms in knowledge-intensive (KI) activities in Brazil, India and South Africa. KI denotes capability levels achieved by firms in the technological trajectory for each of the taxonomic categories of technology.

The incidence of participation of firms in KI activities varied depending on the KI levels. Firms in Brazil enjoyed the lead on level 4 KI activities. The incidence of participation of automotive firms in level 4 human resource and process technology KI activities in Brazil (88%) was higher than firms in India (84%) and South Africa (82%). The breakdown for product technology was 88 per cent for Brazil, 82 per cent for India and 80 per cent for South Africa.

Firms in India enjoyed a lead on the level 5 KI activities over firms in South Africa and Brazil. The incidence of participation of automotive firms in level 5 human resource and process technology KI activities was 78 per cent in India compared to 72 and 68 per cent respectively in South Africa and Brazil. The breakdown on product technology was 70 per cent among firms in India, 68 per cent among firms in Brazil and 65 per cent among firms in South Africa.

Firms in India (48% for HR and PT and 38% for product technology) enjoyed a lead over Brazil (42% for HR and PT and 30% in product technology) and South Africa (38% for HR, 27% for PT and 18% for product technology) in the level 6 human resource and technology activities.

The results show that firms in Brazil enjoyed a higher lead over firms in India and South Africa in the capability of adaptation and supporting improvements to process and product technologies. Firms in India enjoyed a lead in process engineering and new product development capabilities over firms in Brazil and South Africa. The higher intensity of human capital and networking strength seems to have helped to support higher firm-level technological capabilities in India than in Brazil and South Africa. Firms in South Africa appear to have the lowest incidence of level 4-6 KI among the three countries.

6.2 Statistical Relationships

The results of the statistical regressions are analyzed in this section (see Table 13). The chi-square (χ^2) test for model fit is significant and all three regressions passed the White test for heteroskedascity.

It can be seen that the integrated variable of SQ is significant and positive in all three regressions. SQ is statistically highly significant (1%) in the HR and PT regressions and is significant at the 10 per cent level in the RD regression. The results show that HR, PT and RD of automotive firms in the three countries pooled are positively correlated with the systemic pillars. Interestingly, despite below average high tech support, the exceptionally

Table 12: Technological Depth of Automotive Firms, Brazil, India and South Africa, 2002

KI	Human Resource			Process Technology			Product Technology		
	Brazil	India	S.Africa	Brazil	India	S.Africa	Brazil	India	S.Africa
1	34 (100)	50 (100)	55 (100)	34 (100)	50 (100)	55 (100)	34 (100)	50 (100)	55 (100)
2	34 (100)	49 (98)	54 (98)	34 (100)	49 (98)	54 (98)	34 (100)	49 (98)	53 (96)
3	34 (100)	47 (94)	50 (90)	34 (100)	47 (94)	50 (90)	32 (94)	45 (90)	47 (86)
4	30 (88)	42 (84)	45 (82)	30 (88)	42 (84)	45 (82)	30 (88)	41 (82)	44 (80)
5	23 (72)	36 (78)	43 (68)	23 (72)	36 (78)	43 (68)	22 (68)	34 (70)	39 (65)
6	13 (42)	24 (48)	23 (38)	9 (42)	24 (48)	23 (27)	6 (30)	15 (38)	21 (18)
N	34 (100)	50 (100)	55 (100)	34 (100)	50 (100)	55 (100)	34 (100)	50 (100)	55 (100)

Note: Figures in parentheses refer to percentages of surveyed firms in each country.
Source: Compiled from UNU-MERIT (2003-2004) survey.

Table 13: Technological Capability and Systemic Quad, Brazil, India and South Africa, 2002

	HR	PT	RD
SQ	0.32 (9.06)*	0.46 (8.68)*	0.05 (1.75)***
FO	0.07 (2.50)*	0.04 (1.07)	0.04 (1.79)***
X/Y	-0.03 (-0.67)	-0.09 (-1.31)	0.11 (2.53)*
S	0.02 (0.71)	0.01 (0.32)	0.03 (-1.36)
μ	-0.22 (-2.32)**	-0.63 (-4.45)*	0.00 (-0.03)
N	139	139	139
χ^2	27.97*	28.99*	29.85*

Note: Figures in parentheses are z-ratios; *, ** and *** are statistical significance at 1%, 5% and 10% levels; regressions include country dummies.
Source: Computed from UNU-MERIT (2003-2004) survey.

high supply of human capital has stimulated foreign firms to participate in designing and other R&D activities. The high share of human capital in the workforce, especially in India, has been instrumental in producing a strong and positive relationship between HR and FO.

Among the statistically significant results, FO and X/Y are also positively correlated with some of the technological capability variables. The coefficient of FO had a positive sign in all the three technological capability regressions and is statistically significant in the HR and RD regressions, while export intensity is positively correlated with RD. Size did not matter at all in all three regressions demonstrating the irrelevance of scale in automotive parts and component firms.

Despite low exposure to export markets, firms in India enjoyed a slight edge in technological capabilities over firms in Brazil and South Africa because of its much higher skill intensity and stronger networking with institutions. Overall, the incidence of firms' participation in the higher knowledge intensive activities ranging from 4-6 is fairly strong in all three countries with firms in Brazil enjoying the highest incidence. Firms in India enjoyed higher incidence of participation in level 5-6 KI activities than firms in Brazil and South Africa. The statistical results confirmed the significant and positive relationship between firm-level technological capabilities and the systemic quad. FO enjoyed a positive relationship with HR and RD, while X/Y enjoyed a positive relationship with RD.

7. Conclusions

This paper examined the state of the embedding systemic support and firm-level technological capabilities and the relationship between the two, from a sample of automotive firms in Brazil, India and South Africa. Firms in South

Africa enjoyed the best overall basic infrastructure compared to firms in India and Brazil. The high tech infrastructure facing automotive firms in the three countries was similar. In India, weaker standards organizations were offset by strong supply of human capital. Firms in India enjoyed stronger network cohesion followed by firms in Brazil and South Africa. Brazil enjoyed strongest integration with global trade markets – in both export and import markets – followed by South Africa. Firms in India enjoyed much less exposure to export and import markets compared to firms in Brazil and South Africa.

Firms in India on average enjoyed slightly higher HR, PT and RD capabilities than firms in South Africa and Brazil. The higher skill intensity and network cohesion has offered firms higher intensity of participation in HR and PT activities in India compared to firms in South Africa and Brazil. The higher skill intensity levels have also allowed firms in India to rework and automate older machinery and equipment in India. Although firms in Brazil show the highest mean R&D expenditure in sales, India followed by South Africa showed higher R&D personnel in the workforce. Whereas firms in Brazil enjoyed significant R&D support from external domestic institutions, firms in India and South Africa tended to undertake them more in-house.

Firms in Brazil enjoyed the highest incidence of participation in level 4 KI activities while firms in India show the highest incidence of participation in levels 5 and 6. The lack of exposure to foreign import and export markets in India seems to have been offset by stronger support from human capital and networking. Exports to the developed economies and the failure of the domestic intellectual property rights regime seems to have encouraged higher patent take up in the United States by firms in South Africa than firms in Brazil and India.

The systemic quad variable enjoyed a positive relationship with all the three technological variables – HR, PT and RD. The relationship was particularly strong between SQ and HR and PT. Firms in the three countries appear more reliant on domestic institutions for their HR and PT activities than for RD activities. Whereas contract R&D appears important in Brazil, considerable amounts of RD activities are internalized in India and South Africa. The positive and strong relationship between FO and HR shows that foreign firms have taken advantage of the supply of human capital to support high capabilities of HR. Also, foreign firms have absorbed best HR practices from their plants abroad by taking advantage of high skill capabilities available at the host-sites. The statistically significant and positive relationship between X/Y and FO, and RD shows that export markets and foreign ownership have also been important in stimulating firms' participation in R&D activities. The positive and statistically significant coefficient of foreign equity in the pooled sample demonstrates the potential for strong human resource and R&D spillovers from foreign to local automotive firms.

Appendix 1: Correlation Coefficients of Independent Variables, Brazil, India and South Africa, 2002

	SQ	FO	X/Y	S	Age	Country
SQ	1.00					
FO	-0.21	1.00				
X/Y	0.16	-0.01	1.00			
S	0.21	-0.21	0.23	1.00		
Age	-0.18	0.20	-0.34*	-0.51*	1.00	
Country	0.13	-0.02	0.16	0.25	-0.54*	1.00

Note: * – too high correlation.
Source: Computed from UNU-MERIT (2003-2004) survey.

Notes

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1. The significance of trust in raising economic performance was earlier noted by Mill (1994).

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